SECTION III. KOKO CRATER AND KAAU CRATER DESIGN

A. TECHNICAL DATA

1. General

This section summarizes the results of field work, literature surveys, and current utility analysis to expand the data base for realistic design concepts for the Pumped Storage Hydroelectric (PSH) projects. The projects could then be evaluated for technical, economic, and environmental feasibility. The following sections discuss geotechnical, hydrological, utility system analysis, and ocean engineering issues. (See Appendices E, F, and G technical reports for more detail.)

2. Geotechnical

a. Koko Crater (See Plate 1 of Appendix E for project location and plate 2 for Geologic description)

Borrow material: Considering the weak to moderately strong nature of the Koko Crater tuff, local borrow sites will likely yield earthfill-type material rather than rockfill material. The tuff derived earthfill material, however, will likely be highly erodible on embankments and some measures will be needed to prevent erosion and piping should seepage occur.

Construction: To reduce the amount of settlement the dam will experience, over-excavation of the alluvial materials at the crater gap will likely be required. Alluvium at the crater gap was observed to be at least 20 feet thick where exposed in the stream course draining the crater. The tuff and alluvium within the crater, in general, appear to be highly permeable and it is likely that lining of the reservoir will be needed to reduce the potential for large losses of water through infiltration. Tunnel excavation appears to be feasible using currently established methods; however, considering the nature of the tuff, the need for temporary crown support should be anticipated. Where tunneling extends below sea level, basal groundwater will be encountered and, due to the highly permeable tuff excavation, will require groundwater control measures such as grout curtains and dewatering. These measures will be particularly difficult for the powerhouse site because of the large underground openings required. Based on the performance of the existing road cuts along Kalanianaole Highway vertical rock faces should have very good standup time.

Geological Hazards: It does not appear that the project would adversely affect stability of the slopes in the area. The possibility of rockfall and rock sliding, however, will continue to exist on the steep slopes above the reservoir. The island of Oahu is not considered a highly active seismic area and the project would be designed to the prevailing code related to seismic zone 2A. Although Koko Crater is believed to be approximately 32,000 years old, many geologists would consider Koko Crater to be a potentially active crater. This potentiality should be tempered by the trend in volcanic activity in the Hawaiian Islands moving to the southeast, suggesting that the likelihood of volcanic activity on Oahu during the lifespan of the project is relatively low. Since the Koko Crater reservoir site is located sufficiently inland and at a high enough elevation the possibility of inundation of the reservoir by a tsunami is remote; however, the breakwater and other appurtenances on the ocean side of the project could suffer severe damage. Finally, ground subsidence resulting from the consolidation of soft sub-soils does not appear to be a consideration for the project.

b. Kaau Crater Project (See Appendix E Plate 3 for project location and Plate 4 for Geologic description)

Borrow material: Spur ridges in the Maunawili reservoir area appear to be potential sources of basalt rockfill material. Basaltic rock characteristics on the rim of the Kaau Crater should also have characteristics appropriate for use as rock fill. Deposits of low permeability material suitable for dam clay core or reservoir lining were not observed in any sufficient quantities. Silts and clays within the Kaau Crater may be suitable for use as liner material for the Kaau reservoir since these materials currently function to some extent as a natural liner in the crater contributing to its marshy surface condition. However, soft soil and shallow ground water conditions would present difficulties that would need to be overcome to process the silts and clays.

Construction: To reduce the amount of settlement the Maunawili dam will experience, over-excavation of the alluvial materials will likely be required. Once basalt rock foundation conditions are exposed, probing to detect possible voids may be required. With appropriate design and construction techniques basaltic rock at the dam abutments should provide adequate foundation support for dam construction. The alluvium and basaltic rock at the Maunawili site appear to have high permeability and lining of the reservoir should be anticipated.

Although silts and clays in the bottom of the Kaau Crater appear to have low permeability characteristics, the transition slopes around the perimeter of the crater floor may have high permeability. Lining of the reservoir will be needed to reduce the potentially large losses of water through leakage. The crater floor appears to be highly compressible and may experience significant settlement under reservoir loading.

Tunnel construction considerations for the Kaau project are similar to the Koko Crater project except for the major dike complex system that pervades the geological formation between the crater and the lower reservoir of the Kaau project. It is likely that abrupt changes in groundwater levels will be encountered during tunneling through the diked complex. Appropriate exploration and tunneling methods will need to be used to reduce the potential construction and safety problems associated with sudden, large volume flows of groundwater in zones of sheared rock. The presences of groundwater will require design and construction features for the underground power plant to assure positive control of groundwater infiltration.

Geological Hazards: Areas of debris flows and debris avalanches are located above both reservoir sites. The volumes of material involved are likely to be small; therefore, a significant impact on reservoir level is not anticipated. The seismic and volcanic conditions are similar to the Koko Crater description. The Kaau Crater and Maunawili reservoirs are sufficiently inland and at high enough elevations that the possibility of inundation by tsunami is non-existent; however, intense rainstorms can cause localized flash floods that may transport mud and rock debris into the reservoirs.

3. Ocean Engineering

a. General

Appendix F discusses the ocean environment and recommends design requirements for the salt water intake/outlet structure of the Koko Crater project. The structure is located about one-quarter mile southwest of the Blowhole near the shoreline below Kalanianaole Highway. Figure 2 of Appendix F depicts its location. The inlet/outlet structure must be designed to withstand forces created by wind driven waves during both the construction phase and when in operation.

This study considered two options for the inlet; a continuous tunnel out to deep water, and a near shore inlet protected by a breakwater that encloses a salt water reservoir. During operation the breakwater must be pervious to allow water flow in both directions. This feature will filter large objects from entering the inlet tunnel leading to the power plant.

Continuous Tunneling: In this option the inlet/outlet would be extended sufficiently offshore such that it would not be subject to large breaking waves. Based on the estimated bathemetry it would be necessary to extend the tunnel about 500 feet offshore to a bottom depth of 65 feet to provide a cover depth of about 30 feet over the tunnel. This location will avoid the affects of 30 foot design waves for the area. This option is depicted in figure 7a of appendix F.

Breakwater: This option requires the initial construction of a cofferdam so that the inlet/outlet structure can be constructed in the "dry". An offshore breakwater is also necessary to provide wave protection during construction and operation. The breakwater can be located relatively near shore; it is estimated that a location 150 feet offshore will be sufficient primarily to provide working space during construction of the inlet/outlet structure. The breakwater would be a rubblemound structure which would dissipate wave energy and serve as a "filter" for large objects. Figure 8 of Appendix F shows a conceptual typical section for the breakwater.

4. HECO System Analysis

The Generation Expansion Planning Program Study (GEPPS) and PROSCREEN:

GEPPS and PROSCREEN are computer programs used to model and simulate utility system operations and to perform screening of different basic plans of generating facilities and demand side programs. The computer programs were used as part of the IRP work, discussed above, as part of a complete generation expansion study. The identification of PSH as an economically feasible addition to the HECO generating system resulted from the GEPPS and PROSCREEN analysis.

Additional analyses were performed as part of the present study to utilize the most current load forecasts. Appendix G is the report on the results of the analyses. These results indicate that the inclusion of PSH in the mix of generating facilities in the year 2005 would result in fuel savings over mixes of generating facilities that did not have PSH. The study further showed that a daily operating cycle would have greater fuel savings than a weekly operating cycle.

The analysis concluded that the number of pumping hours should be about 8 and the number of generating hours should be up to 14, and the size of the PSH facility should be in the range of 100 to 180 MW. 180 MW is the upper limit so as not to increase spinning reserve requirements. (Spinning reserve is equal to the largest unit on the HECO system which is presently 180 MW.)

As a result of these analyses and the capacity of the Koko Crater project both Kaau and Koko Crater projects are based on a nominal 160 MW generating capacity.

5. Hydrogeology

Koko Crater: As noted above, any groundwaters encountered in the construction of this project are likely to be brackish due to the close proximity of the project to seawater. Because of the relatively dry nature of the area due to the low annual rainfall there are no perennial streams or other fresh water resources of concern for this project.

Kaau Crater/Maunawili Project: Unlike Koko Crater, the Kaau Crater project is significantly affected by the hydrological features of the area and related legal requirements; both current and anticipated in the future. The Kaau Crater/Maunawili project is affected by the following major issues:

- Source and availability of water to initially fill the reservoir
- Affect of diked waters on the routing and construction of shafts and penstocks
- Requirements to maintain stream water quality
- Requirements to maintain delivery of water to users
- Requirements to maintain in-stream flow

Each of these issues is discussed in the following sections preceded by a general description.

a. General Description of area

The area encompassing Kaau Crater and the Maunawili Valley is one of the wettest spots in East Oahu. The annual median rainfall pattern in this region shows the dominance of the topographic effects on rainfall. The principal rain-producing mechanism on Oahu is orographic lifting of trade winds along the Koolau slopes. These slopes terminate at the crest of the Koolau Range which divides Kaau Crater from the Maunawili Valley.

The geological structure separating these two features, as well as the area underlying the Valley, contains large quantities of dike impounded water. The dike-impounded water manifests itself as essentially continuous flow out of natural springs, seepage and manmade tunnels that feed the streams in the Valley. The effect the dike system has on ground water levels is depicted in Figure III-1. The flow quantities and the streams created by this groundwater are depicted in Figure III-2.

b. Reservoir Water Requirements

The amount of water required for the Kaau Crater project is about 1470 acre-feet or 485 million gallons. The possible sources for this water are the springs and tunnel feeding the Maunawili Stream, additional wells and tunnels into the dike impounded groundwater, and rainfall.

The dry weather water sources feed the Maunawili Stream at about 1 million gallons per day. Assuming a constant flow, it would require over a year to fill the reservoir; (evaporation is assumed to be equal to recharge by rainfall into the reservoir.) however, as shown on Figure III-1, some of the principal sources of water flowing into the stream will be covered as the reservoir fills thereby applying a back pressure on these sources. This backpressure would be expected to reduce the flow from these sources and increase the time for filling.

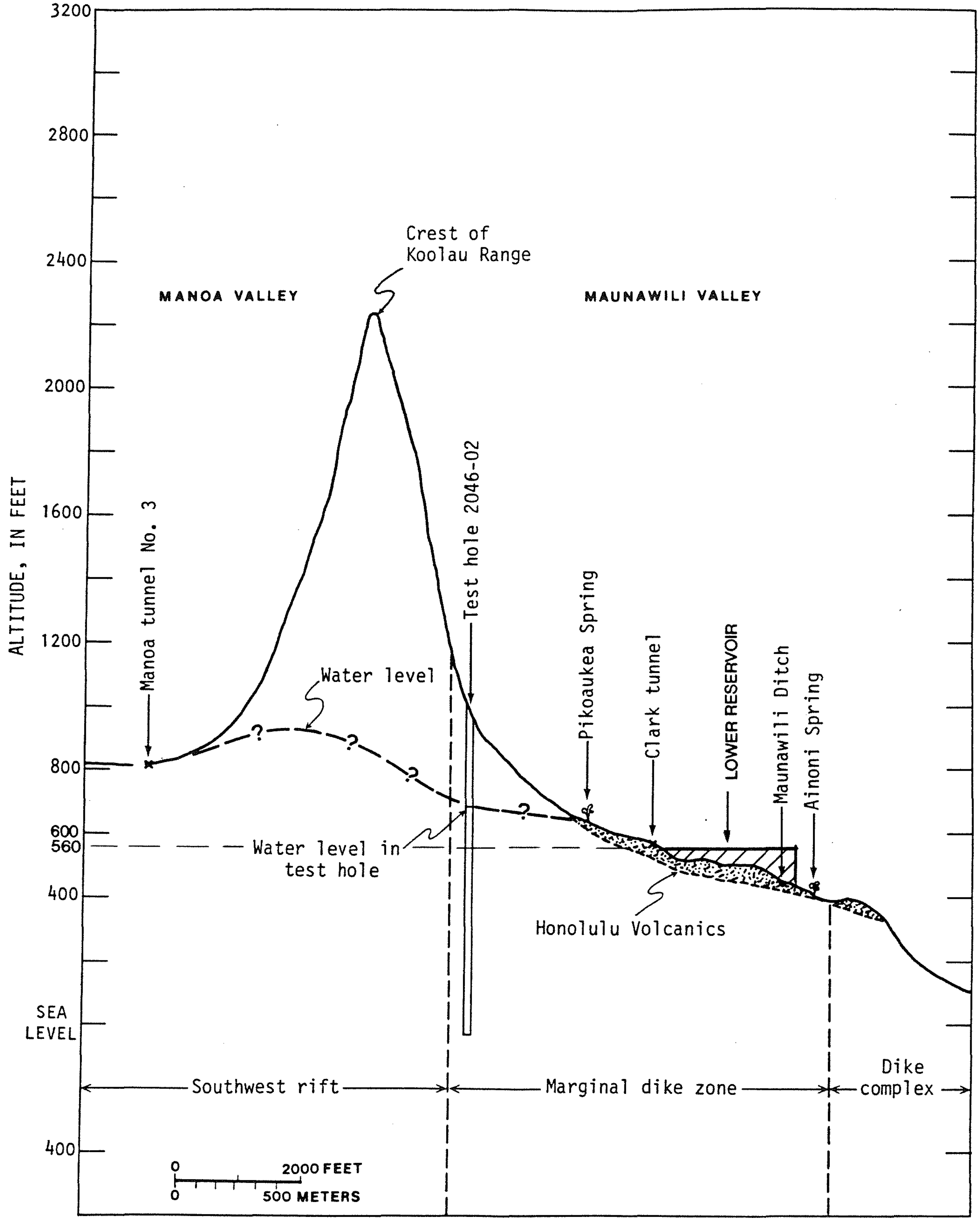
To accelerate reservoir filling it is conceivable to install wells to tap the marginal dike groundwater. As noted in "Water Resources of Windward Oahu",(Takasaki et. al. 1969) the basal water level of Maunawili Valley is at an elevation of 2 feet and the high level (diked) water is at 650 ft. These conclusions are based in part on a series of test wells drilled for the Honolulu Board of Water Supply during 1953-54 to investigate ground water resources in Maunawili Valley.

These wells (now identified by Well Nos. 2046-01, 2046-02, 2047-01 and 2047-02) encountered ground water at about 600 ft above sea level. The geological information presented in the report indicates that the test wells penetrated marginal dike complex formations and that the rocks have low to moderate permeability.

In general, the rocks of the marginal dike complex of the Koolau Volcanic Series have relatively low permeatabilities and do not freely yield water to wells. The available information indicated that, on the Windward side of Oahu, wells have specific capacities of less than about 50 gallons per minute per foot of drawdown. By comparison, wells tapping dike-free flows of the Koolau Volcanic series have specific capacities ranging from about 80 to 500 gallons per minute per foot of drawdown. (Takasaki et. al., 1969). To fill the reservoir from these sources in a period of from 3 to 6 months would require wells with a capacity of 2 to 4 Mgal per day. The low permeatabilities of the marginal dike complex essentially eliminated wells as a source of water to fill the reservoir.

The same report noted that further development of water flow by the addition of more horizontal tunnels in the marginal dike zone or anywhere in Maunawili Valley would not enhance the existing net water supply. The principal reason is that the base-flow discharge is too small and that the present tunnels are already effective in channeling nearly all base flow above the Maunawili Ditch.

The historical rainfall data suggests that in an average year the drainage area related to the lower reservoir could fill the reservoir in about 6 months (as compared to 12 month period of dry weather flow from the diked zones only). To capture this water



EVALUATION OF MAJOR DIKE-IMPOUNDED GROUND WATER RESERVOIRS, ISLAND OF OAHU

GEOLOGICAL SURVEY

FIGURE III-1

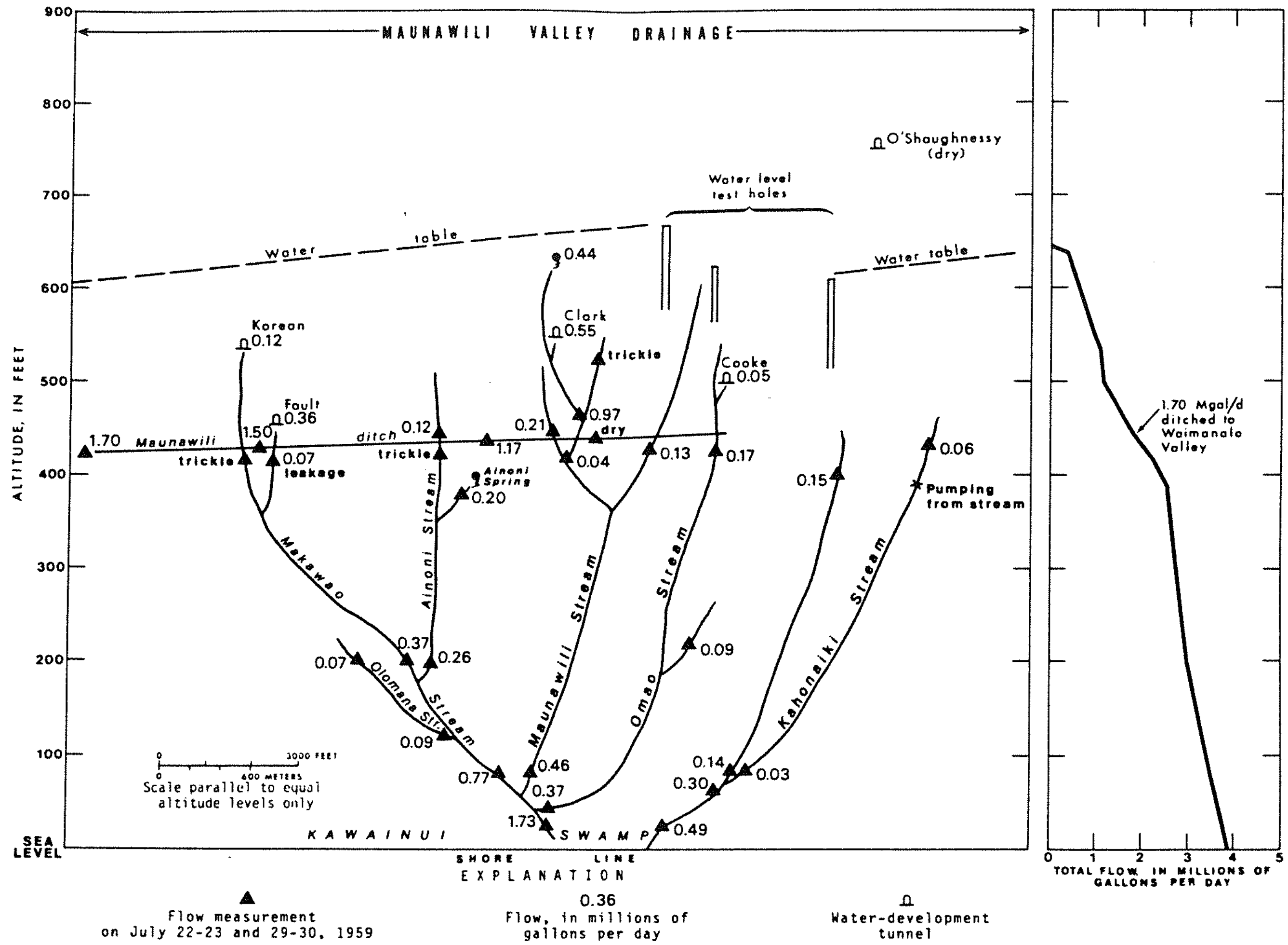


Figure 30. Relative altitudes of water levels in wells, water-level gradient of dike-impounded water, tunnels, and base-flow measuring points in streams in Maunawili Valley.

EVALUATION OF MAJOR DIKE-IMPOUNDED GROUND-WATER RESERVOIRS, ISLAND OF OAHU	GEOLOGICAL SURVEY	FIGURE III-2

would essentially eliminate the contribution of water flowing to the Waimanalo Ditch as well as the Kawainui Marsh during the filling cycle.

c. Affect of diked/perched water on Penstock routing and construction

The diked water is in the path of the waterways between the upper and lower reservoirs. In Figure III-1, it can be seen that the groundwater level (based on test wells) is at 800 to 600 feet above sea level as the Koolaus are traversed. Since the inlet to the lower reservoir is at about 500 feet a significant length of the underground waterway will traverse through ground water regions. This condition will impose water intrusion control procedures that will add significantly to the cost of construction.

The amount of water encountered may be reduced by routing the penstock from the upper reservoir (its base is at elevation 1540 ft) at a shallow slope toward the Maunawili Valley thereby maintaining the tunnel above the maximum water level in the Koolau's.

d. Water Quality

Many laws and regulations, both federal and State, require that the water quality of the streams that drain the Maunawili valley be maintained and that pollutants that would affect in- stream habitat, the Kawainui Marsh, or agricultural lands be eliminated. During construction of the lower reservoir it is almost certain that a change in the nature of the nutrients and other elements flowing into the streams will result from excavation and any subsequent erosion due to rain. The excavation alone will undoubtedly disrupt or destroy insect, mammal, and bird populations and habitats resulting in a major change in the flow of organic as well as inorganic material into the streams. It is unclear that it is possible to maintain water quality should construction of the Kaau crater project go forward.

e. Water Quantity

Maunawili Ditch: The Maunawili Stream and its tributaries currently contribute about 1 million gallons of water a day to the Maunawili Ditch. This ditch provides irrigation water to the Waimanalo Irrigation System. The February 1992 draft report on the State Water Projects Plan indicates that the supply of water for irrigation is expected to increase and continue for the foreseeable future. (The report has projections out to the year 2010).

III B. PUMPED STORAGE TECHNOLOGY

"Hydroelectric pumped storage...is widely recognized as the most mature and efficient energy storage technology available. There are more than 180 pumped storage plants in operation worldwide with a total installed capacity exceeding 70,000 MW."

This quotation from a 1993 paper presented by Mr. R. S. Koebbe of L. B. Industries at the Waterpower '93 Conference supports the validity of considering PSH technology for use with the HECO utility system. As an established technology there is no research to be undertaken and there are a variety of firms, foreign and domestic, to produce the necessary machinery and numerous contractors available with the required construction knowhow. Table IIIB-1 is a summary of pumped storage hydroelectric facilities worldwide.

Pumped storage facilities generally use fresh water as the pumping fluid; so essentially all the experience is limited thereto. The only major salt water plant is a unit currently under construction in Okinawa. This unit is a 30MW plant that is expected to be completed in 1998. (Construction was delayed by phased government funding). Even with the salt water application the machinery is based on proven design concepts; the major difference from a fresh water plant is in the materials of construction for the impellers/runners. Appendix I provides more detail on the Okinawa project.

Installed capacity of pumped-storage plants by country

Data are based on the surveys "The world's hydro resources" and "The world's pumped-storage plants" in the *Water Power & Dam Construction* Handbook 1991. The numbers of plants exclude pumping only plants at pumped-storage projects.

Turbining capacity of pumped-storage plants in operation, under construction and planned, by country

Country	In operation: Number of plants	In operation: Total capacity (GW)	Under const.: Number of plants	Under const.: Total capacity (GW)	Planned: Number of plants	Planned: Total capacity (GW)
Argentina	2	0.862[a]	0	0	0	0
Australia	6	2.565	0	0	0	0
Austria	17	2.081	0	0	5	2.28
Belgium	2[b]	1.211	0	0	0	0
Brazil	4	0.191	0	0	0	0
Bulgaria	2	0.535	1	0.864	n/a	n/a
Canada	1	0.122	0	0	0	0
Chile	1	0.029	0	0	0	0
China	2	0.033	3	1.55	2	2.6
China (Mainland)	1	1.028	1	1.6	1	1.2
China (Taiwan)	3	0.031	0	0	0	0
Czechoslovakia	8	1.349	1	0.65	2	1.7
Finland	0	0	0	0	1	0.45
France	22	4.9	0	0	1	0.5+
Germany	38	5.129	0	0	0	0
Greece	1	0.315	1	0.3	0	0
Hungary	0	0	0	0	1	1.2
India	4[c]	1.389	3	1.333	0	0
Iran	0	0	1	1	0	0
Ireland	1	0.292	0	0	0	0
Israel	0	0	0	0	1	0.5

Country	In operation: Number of plants	In operation: Total capacity (GW)	Under const.: Number of plants	Under const.: Total capacity (GW)	Planned: Number of plants	Planned: Total capacity (GW)
Italy	20	6.15	1	0.338	1	1
Japan	38	17.004	8	5.48	440[d]	329
Korea (Rep of.)	2	1.032	1	0.6	0	0
Luxembourg	1	1.096	0	0	0	0
Mexico	0	0	0	0	8	2.8
Morocco	0	0	0	0	1	0.333
Norway	7	1.239	1	0.6	3	n/a
Philippines	1	0.31	0	0	1	0.31
Poland	5	1.37	2	0.927	n/a	n/a
Portugal	4	0.414	0	0	1	0.136
Romania	6	0.084	0	0	1	1
South Africa	2	1.4	0	0	1	1
Spain	22	4.831	3	1.32	11	n/a
Sweden	3	0.427	0	0	0	0
Switzerland	12	1.178	1	0.003	n/a	n/a
Thailand	1	0.18	1	0.18	2	0.775
Tunisia	0	0	0	0	1	0.3
UK	5	3.023	0	0	0	0
USA	37	17.09	3	1.975	49	18.69
USSR	1	0.225	3	5	4	11
Yugoslavia	3	1.3	0	0	0	0

(a) Los Reyunos: capacity to be increased from 112 MW to 224 MW; (b) Coo-Trois Ponts 1 and 2 are counted as one plant in total; (c) only one of the completed plants (Kadamparai, 400 MW) has operated in the pumping mode; and, (d) timescale for the development of Japan's planned schemes is not available.

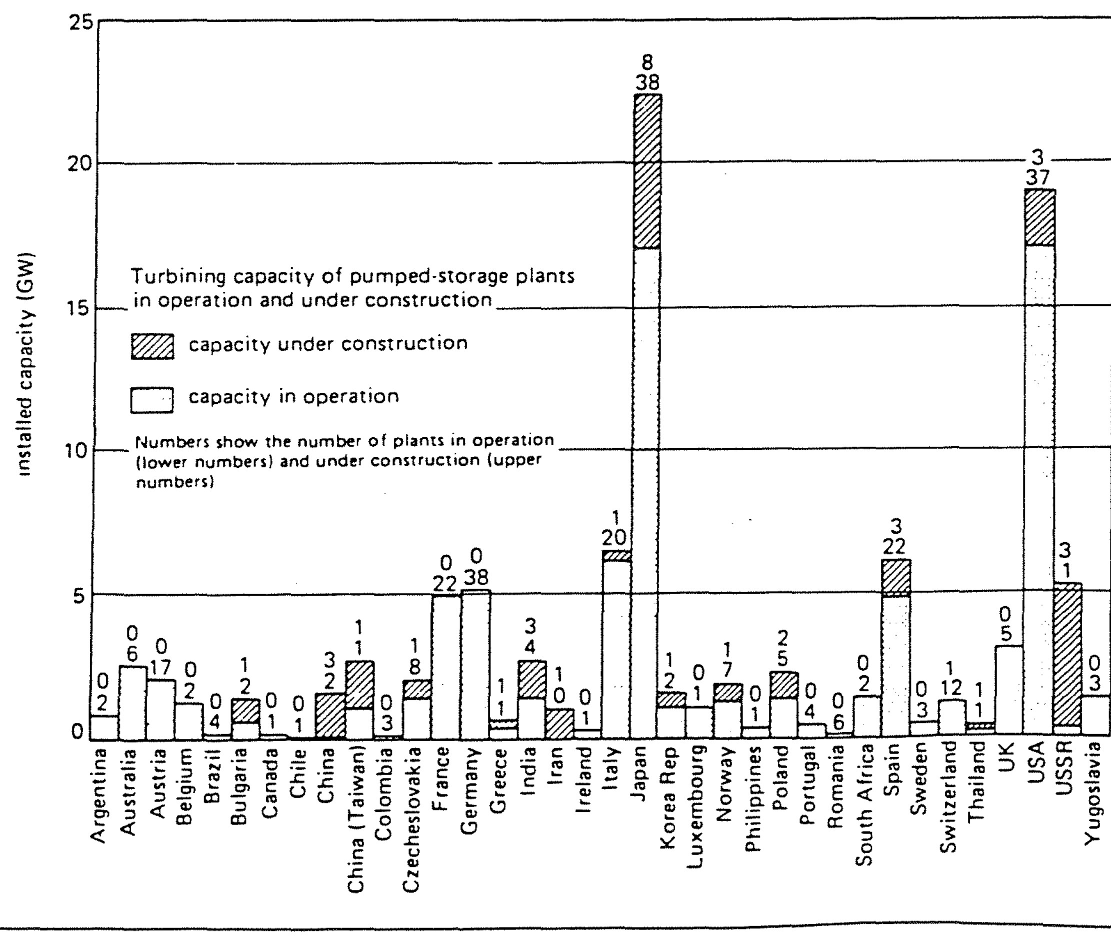


TABLE IIIB-1

C. KOKO CRATER PUMPED STORAGE POWER PROJECT

The Koko Crater site is located on the south-east coast of Oahu just east of Hawaii Kai as shown on Figure III-3. Proposed features of major components of the hydroelectric facility are shown on the following page.

The environmental impact of the Project would be minimized by locating underground most of the power structures, and locating in the Koko Crater the upper reservoir. Furthermore, maximum emphasis and care taken to ensure minimal disturbance of the Project area by minimizing the effect of noise, vibration and visual impact..

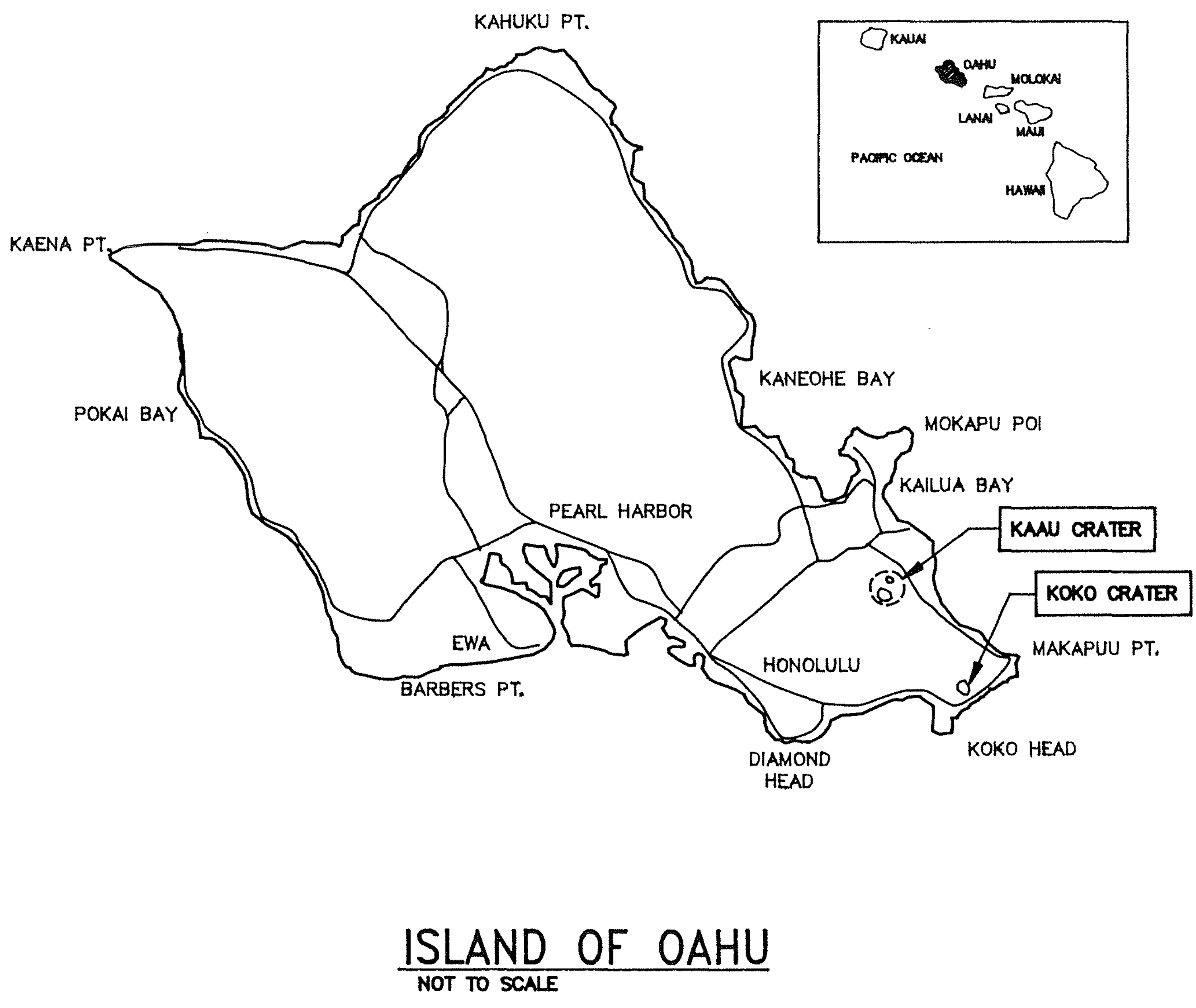
Preliminary plans and profiles of the project showing the major components are provided on Figures III-4 to III-9. Principal features of the Koko Crater are shown in the following:

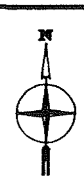
Upper Reservoir

Maximum water level	feet	370
Minimum water level	feet	280
Reservoir bottom elevation	feet	240
Water surface area at Max. water level	acres	50
Water surface area at Min. water level	acres	21
Total storage at Max. water level	ac-ft	3,745
Storage at Min. water level	ac-ft	550
Effective storage	ac-ft	3,195
Available drawdown	feet	90
Dam Type	Earth fill with rubber liner	
Dam crest elevation	feet	380
Dam height	feet	150
Crest length	feet	675
Gross head		
Maximum	feet	370
Minimum	feet	280
Average	feet	340

Design Discharge (Max.)		
Generating mode	cfs	6,440
Pumping mode	cfs	4,830
Head loss		
Generating mode	feet	10
Pumping mode	feet	7
Effective head		
Generating at avg. head	feet	330
Max. pumping height	feet	377
Generating power (Max.)	kW	160,000
(Avg.)	kW	158,000
Pumping power (Max.)	kW	160,000
Installed capacity	MW	160
Number of units	unit	2
Hours of generation	hr	6
Hours of storage	hr	8
Energy storage	MWh	948
Intake-Outlet	Concrete structure of Morning-glory type	
Headrace tunnel		
Length	feet	1,075
Diameter	fee	25
Area	sq. ft.	491
Penstock		
Length	feet	450
Diameter	feet	25
Area	sq. ft.	491
Bifurcation		1
Penstock		
Length	feet	200
Line	No.	2
Diameter	feet	18-15
Area	sq. ft.	254 - 177

Powerhouse		
Type	Underground	
Center of turbines elevation	ft	-165
Turbine	Vertical type of Francis Reversible Pump-Turbine	
Draft Tunnel		
Length	feet	200
Line	No.	2
Tailrace tunnel		
Length	feet	890
Line	No.	1
Diameter	feet	25
Area	sq. ft.	491
Outlet-Inlet	Concrete structure of Horizontal type with Rubblemound Breakwater	
Design seismic intensity	0.15 g	





PROJECT SITE LOCATION

FIGURE III–3

Koko Crater reservoir

Koko Crater would serve as the upper reservoir for the pumped storage facility. The reservoir would be formed by constructing a earthfill-type dam across the northeast portion of the crater rim. The crest of the dam would be at an elevation of 380 feet and the dam would have a maximum height of approximately 150 feet. The crest elevation and inner dimensions of the reservoir were selected so that the volume of earthwork would be balanced inside the crater. Surface alluvium layer of the crater would be excavated by 15 feet deep at minimum. The inner slope gradient of the reservoir is to be 1:3.0 and rubber sheet lining is to be provided to protect the reservoir from seawater seepage. The crest of the dam is to have a free-board of ten feet above the high water level. A spillway and spillway channel are considered unnecessary, because any excess water could be discharged through the water conductor system leading to the powerhouse and sea.

The minimum and maximum operating levels for the reservoir would be 280 feet and 370 feet, respectively. The active storage capacity would be about 3,200 acre-feet.

The surface runoff water in the basin is to be caught in the side gutter of the inspection road and not be allowed to flow into the reservoir. Infiltration and sea water leakage from the reservoir are to be collected through the inspection gallery, where a leakage detection system is also provided, and returned to the reservoir by pump.

A reinforced concrete inlet/outlet structure would be constructed within the crater to direct generation and pumpback flows between the reservoir and the low pressure tunnel. It is to be provided at the southernmost end of the reservoir to shorten the length of the pressure tunnel. A form of the structure is to be a morning glory type of diameter of 90 feet and height 25 feet, which is designed for the maximum hydraulic capacity in both generating and pumping modes.

Powerhouse

A concrete-lined underground powerhouse could be located between the upper reservoir and Kalanianaole Highway 72. The powerhouse and tunnel are located underground to ensure the existing natural scenery is retained. The powerhouse would be of mushroom type sized to accommodate two vertical, reversible pump/turbines directly coupled to motor/ generators. The powerhouse also would have sufficient space for an equipment laydown area for maintenance purposes and for the auxiliary mechanical and electrical equipment. The unit step-up transformers would be placed beside the equipment laydown area.

The setting level of the pump/turbine distributors would be 165 feet below mean sea level to provide the submergence depth required for pumpback operations.

Access to the powerhouse would be by an access tunnel of 0.4 miles and access road 500 feet in length from an above-ground plant substation, which is located in close proximity to an existing sewage disposal facility. A breakwater/outlet access tunnel would be also provided from the powerhouse. In addition, a drainage tunnel would be provided around the powerhouse cavern in order to reduce the leakage of seawater to the cavern by means of grout curtains and drain holes.

Water conductors

A headrace system would extend from the Koko Crater inlet/outlet structure to the powerhouse to convey generation and pumpback flows between Koko Crater Reservoir and the hydroelectric units. The headrace system would consist of a low pressure tunnel, an inclined penstock, and individual unit penstocks.

The low pressure tunnel would extend from the Koko Crater reservoir inlet/outlet structure for a distance of 950 feet to the intersection with the inclined penstock. The penstock would extend downward for a distance of 460 feet to a bifurcation, where individual penstocks would convey discharges to each unit. The penstock and tunnels would have a finished inside diameter of 25 feet. The individual unit penstocks would be reduced to 15 feet in diameter. The penstocks would likely be fiberglass reinforced plastic lined to prevent corrosion and seawater seepage. Furthermore, water conductor drainage systems would collect all the seawater leakage flows.

The tailrace tunnel is to have an inside diameter of 25 feet and the length is to be 890 feet from the bifurcation located 200 feet downstream from the turbine center, and a special coating will be provided at the inner surface of the concrete to minimize adhesion of marine organisms.

Ocean outlet/inlet structure

The reinforce concrete outlet structure is to be constructed at the south side of Highway 72. (Kalanianaole Highway) A curved section is to be provided in the tailrace tunnel at the part where the tailrace tunnel crosses with Highway 72 so that the waterway axis line will be perpendicular to the shoreline.

A rubblemound breakwater is to be provided to protect the outlet structure and suppress water surface fluctuations. It should be constructed prior to other outlet concrete structures, so that a less fluctuating water surface level can be maintained inside.

The invert level of the outlet is to be -50 feet below sea level. The crest elevations of the revetment and breakwater are to be 22 feet and 15 feet, respectively, while the crest width of the breakwater is to be 40 feet.

Special emphasis would be made on the water velocity, of which less than 3.3 feet/sec will be preferable, at the outlet/inlet structure, to protect coral and marine life from the inflow and outflow.

Pump/turbine-motor/generators

Two vertical, single stage, Francis reversible pump/turbine units of 80 MW each would pump water and generate power. However, an alternative of three units of 55 MW each should be studied in the next stage in consideration of the low and variable head, and large discharge. The pump/turbines would be directly coupled to vertical shaft, three-phase, 60 hertz, ac synchronous motor/generators. Corrosion- and salinity-resistant marine materials suitable for seawater application would be used for the pump turbine units. It should be planned to adopt a modified variety of austenite type stainless steel. Emphasis would be placed on minimizing the effects of noise and vibration.

Substation/transmission line

The plant substation would be located at ground level adjacent to an existing sewage treatment plant. An existing HECO 46 kV transmission line should be improved to that of 138 kV to the interconnection at Koolau or Pukele substation, so as to transmit power that is generated and to receive power needed to pump seawater to the upper reservoir.

Project operations

The Project would be operated as a conventional pumped storage hydroelectric facility with the generation cycle occurring during on-peak electrical demand periods and the pumpback cycle occurring during off-peak periods.

The normal daily operating cycle would begin with the upper reservoir at maximum operating level. During the on-peak generation cycle, the hydro units would function as turbine-generators, and water would be conveyed from the upper reservoir to the ocean through the pump-turbines and water conductor system. During the off-peak pumpback cycle, the units would function as pump-motors, and water would be conveyed from the ocean to refill the upper reservoir.

During the daily generating cycle, average plant output would be 158 MW for a period of six hours. During the pumpback cycle, an average of approximately 160 MW plant input would be required for a period of eight hours to refill the upper reservoir. Cycle efficiency is expected to be about 75 percent.

Operation

The PSH facility is proposed to be operated from the switchyard and will have a staff of 15 people to provide operation and maintenance 24 hour, 7 days a week.

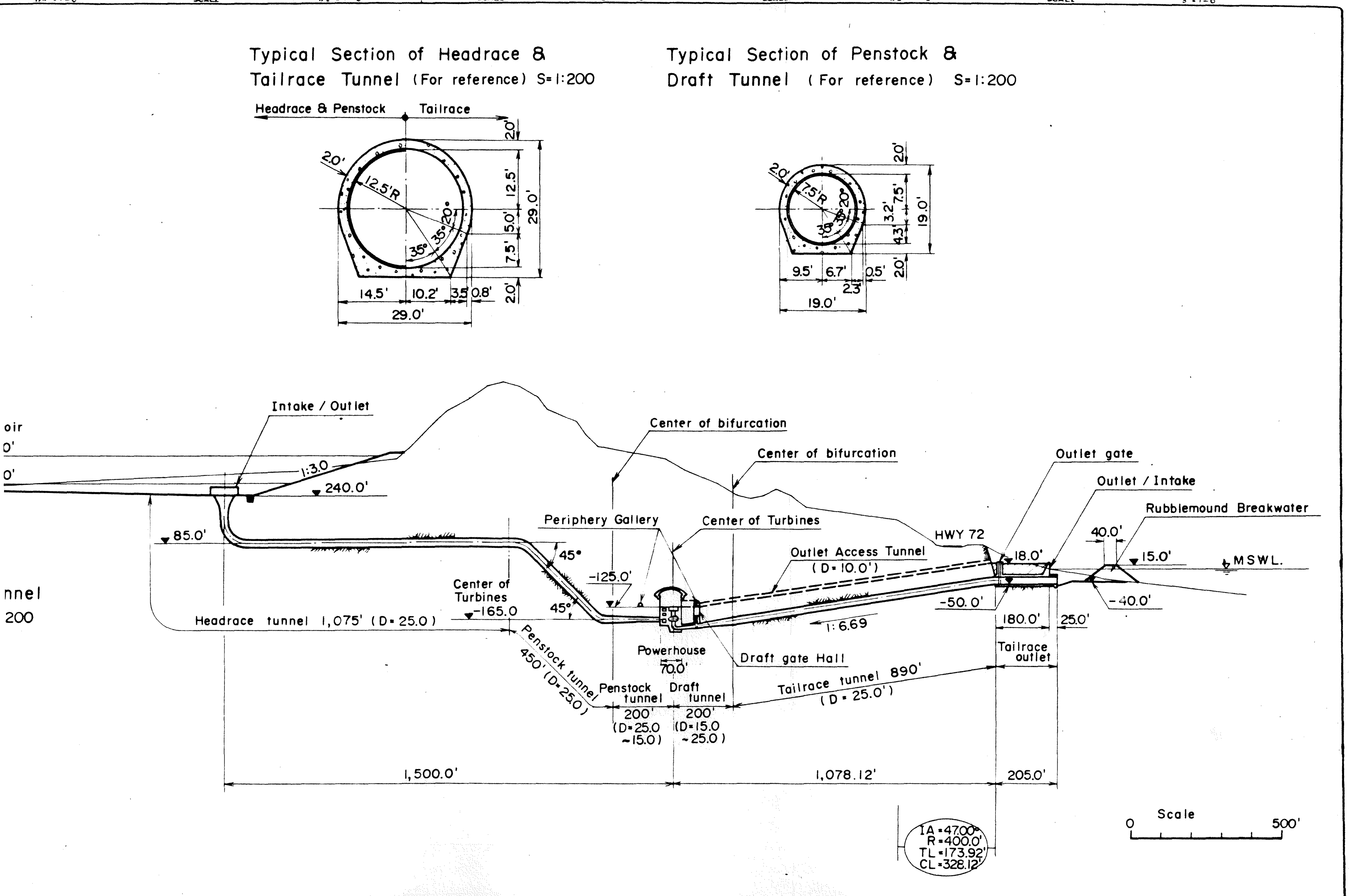


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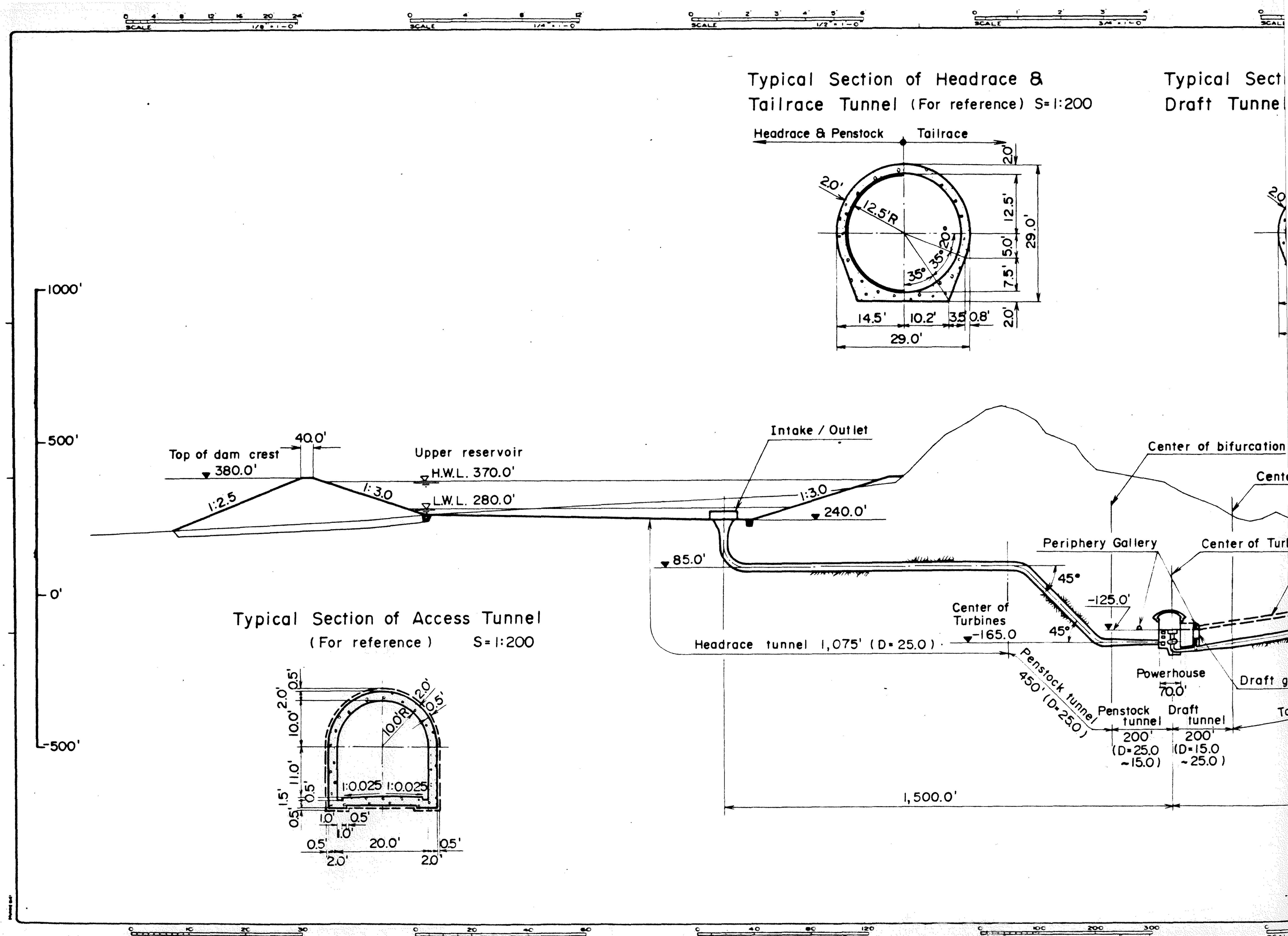
FIGURE III-4



Typical Section of Headrace & Tailrace Tunnel (For reference) S=1:200
Headrace & Penstock
Tailrace
2.0'
12.5'R
12.5'
5.0'
7.5'
29.0'
35°
20°
14.5'
10.2'
3.5'
0.8'
29.0'
Typical Secti
Draft Tunnel
1000'
500'
0'
-500'
Top of dam crest
380.0'
40.0'
1:2.5
1:3.0
Upper reservoir
H.W.L. 370.0'
L.W.L. 280.0'
Intake / Outlet
240.0'
85.0'
Center of bifurcation
Periphery Gallery
Center of Turbines
-165.0
45°
-125.0'
Headrace tunnel 1,075' (D=25.0)
Penstock tunnel 450' (D=25.0)
Powerhouse
70.0'
Penstock tunnel
200'
(D=25.0 ~15.0)
Draft tunnel
200'
(D=15.0 ~25.0)
Draft g
1,500.0'
Typical Section of Access Tunnel
(For reference) S=1:200
0.5'
2.0'
10.0'
10.0'R
11.0'
1.5'
1:0.025
1:0.025
1.0'
0.5'
20.0'
2.0'
SCALE

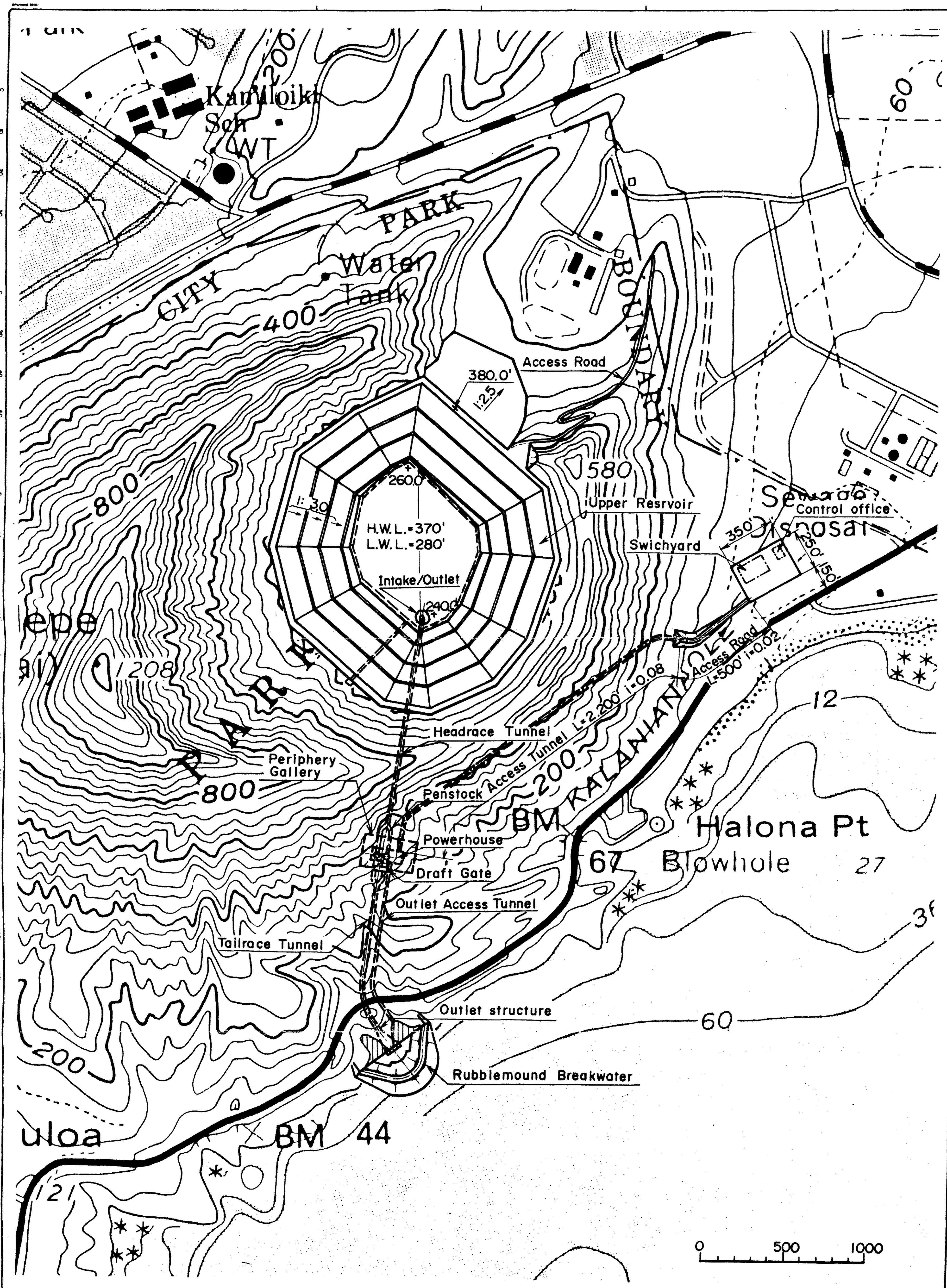


FIGURE III-5

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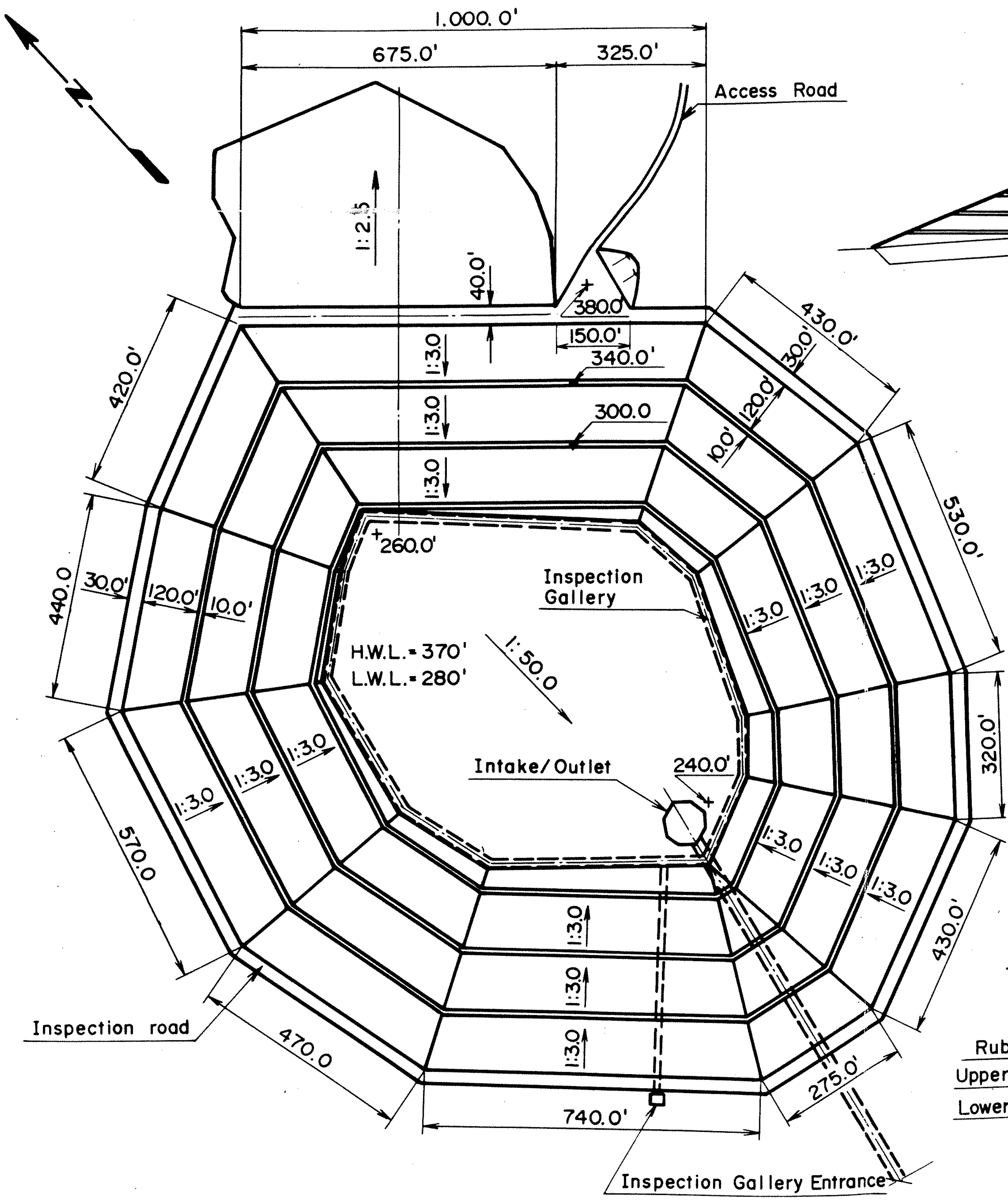
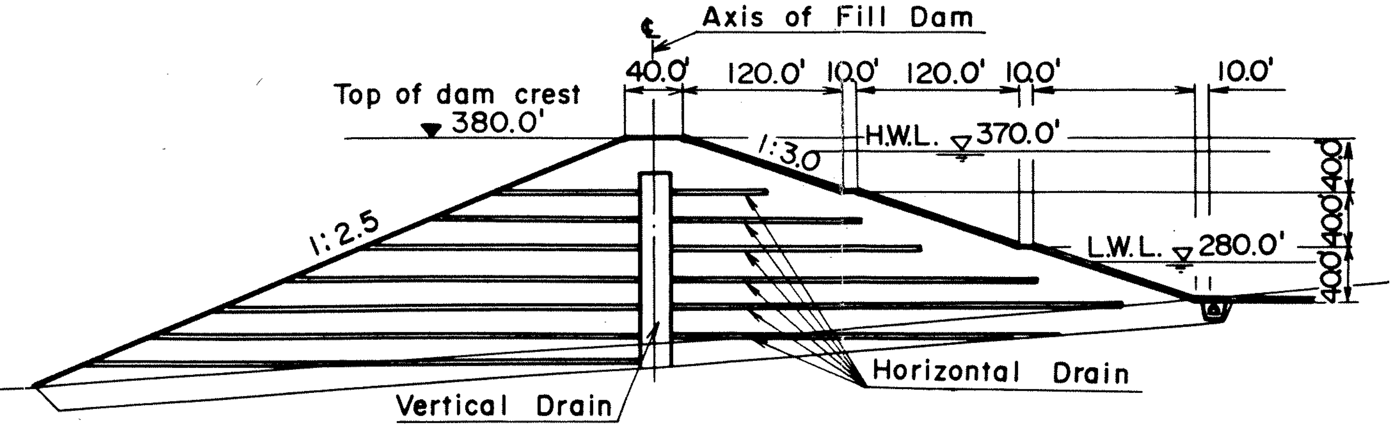
NO.	CO.	REFERENCE DRAWINGS	NO	DATE	DWN	CHK	REVISIONS

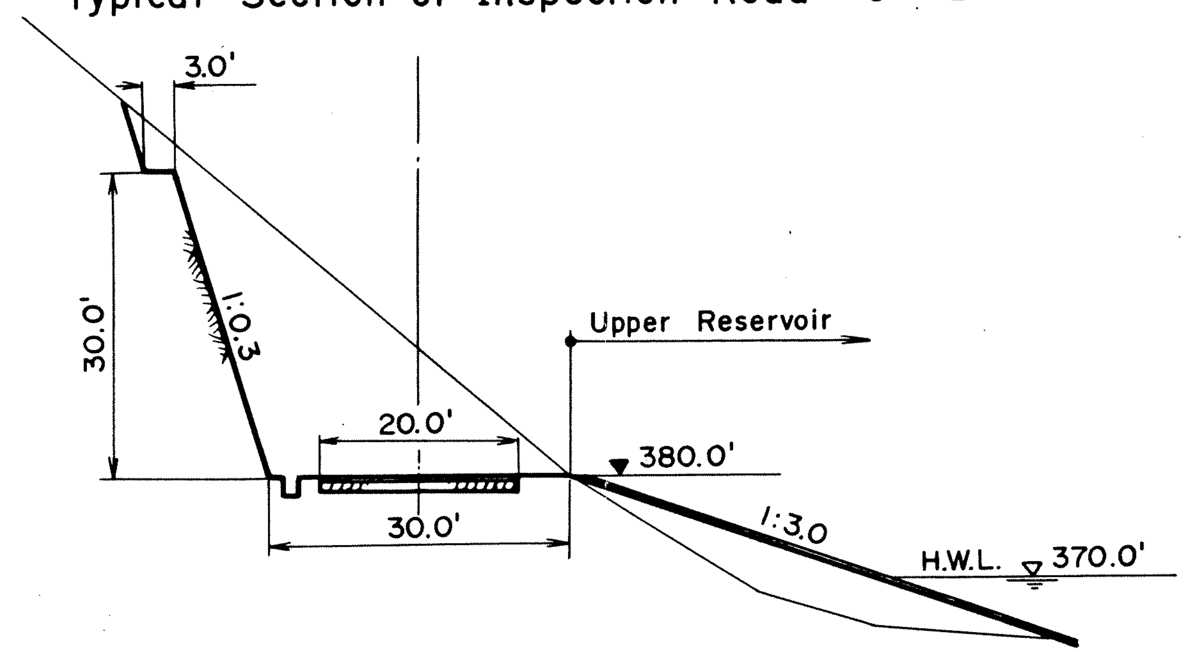
Plan of Upper Reservoir S = 1:3,000



Section of Fill Dam S = 1:1,500



Typical Section of Inspection Road S = 1:200



Section of Inspection Gallery S = 1:100

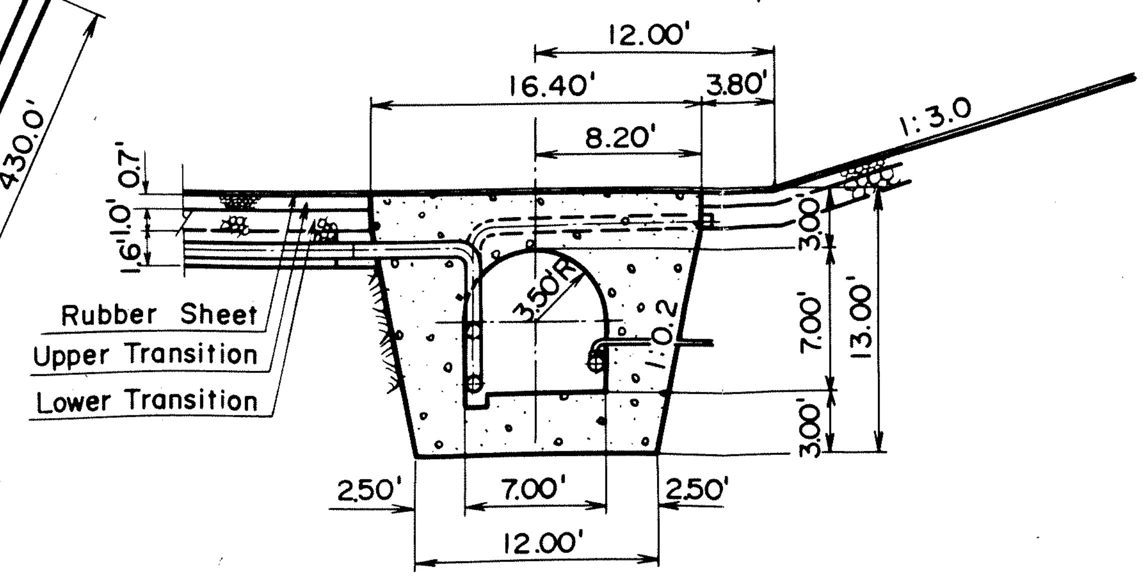


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FIGURE III-6

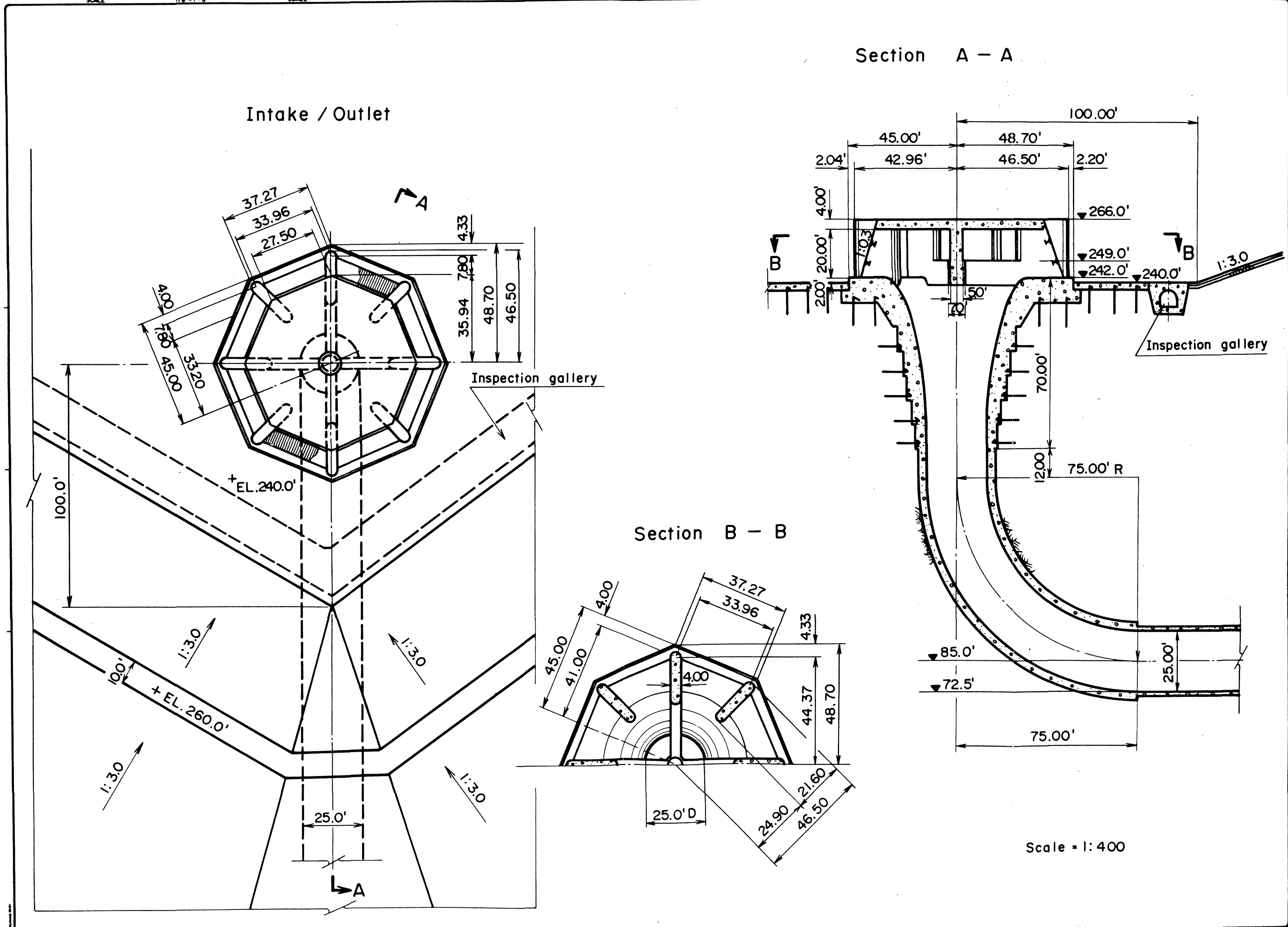


FIGURE III-7

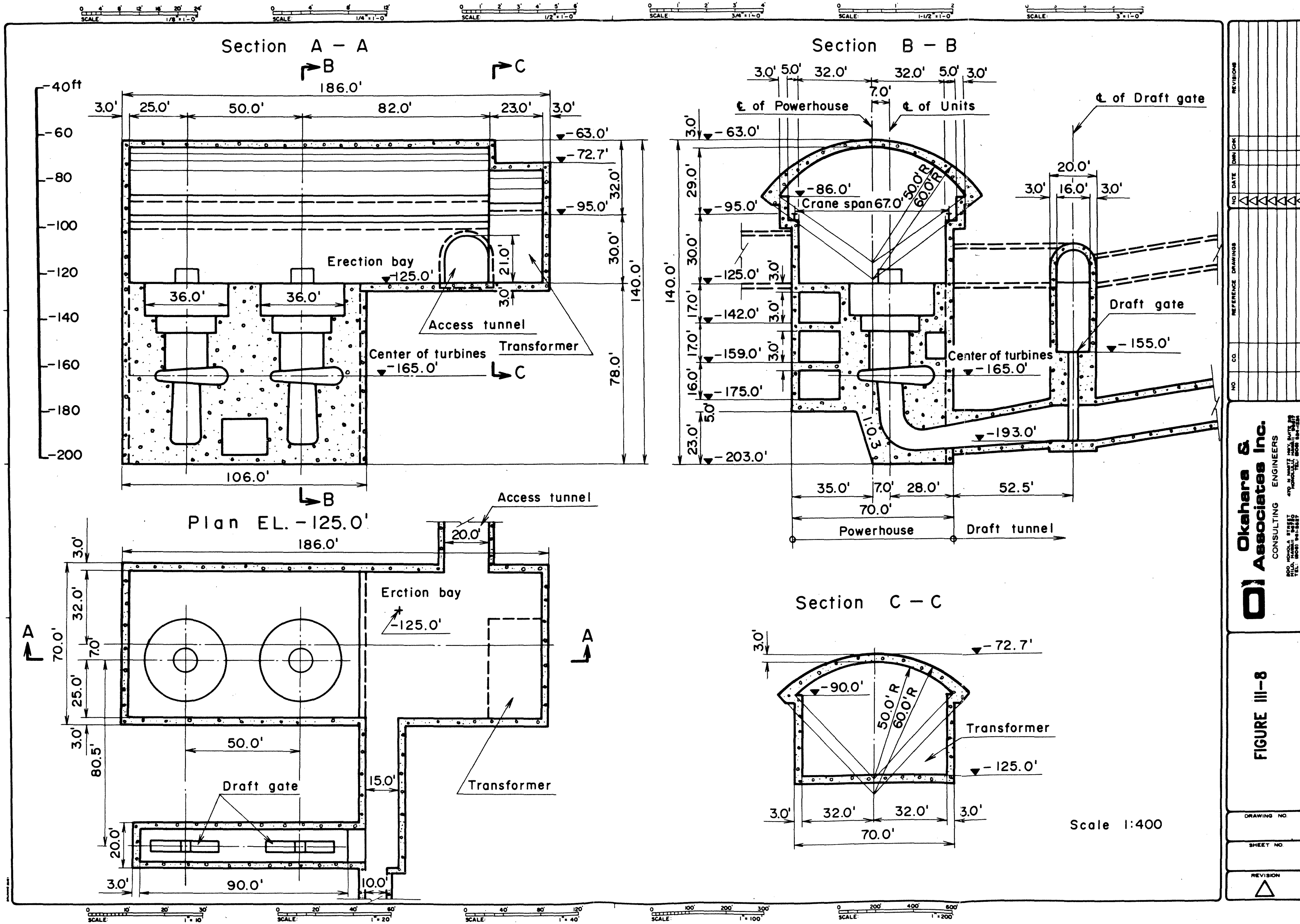
Okahara & Associates Inc.
CONSULTING ENGINEERS

NO	CO.	REFERENCE DRAWINGS	NO	DATE	DWN	CHK	REVISIONS

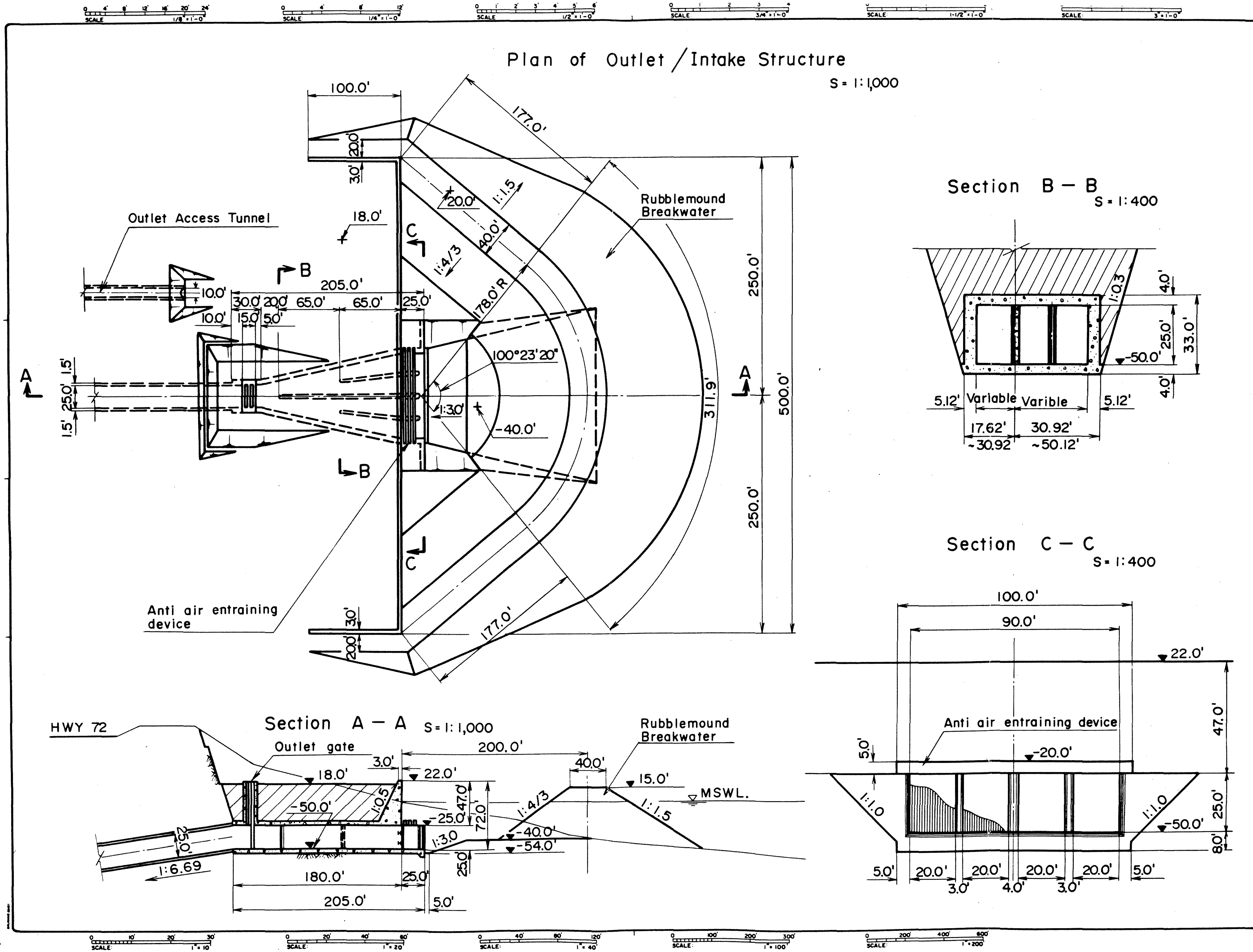
DRAWING NO

SHEET NO

REVISION



Section A – A
B
C
186.0'
3.0'
25.0'
50.0'
82.0'
23.0'
3.0'
-40ft
-60
-80
-100
-120
-140
-160
-180
-200
-63.0'
-72.7'
-95.0'
32.0'
30.0'
140.0'
78.0'
21.0'
3.0'
Erection bay
-125.0'
36.0'
36.0'
Access tunnel
Transformer
Center of turbines
-165.0'
106.0'
Section B – B
3.0' 5.0' 32.0'
32.0' 5.0' 3.0'
7.0'
℄ of Powerhouse
℄ of Units
℄ of Draft gate
29.0'
-86.0'
50.0'R
60.0'R
Crane span 67.0'
-95.0'
20.0'
3.0' 16.0' 3.0'
30.0'
-125.0'
17.0'
-142.0'
-159.0'
16.0'
-175.0'
5.0'
23.0'
-203.0'
Draft gate
-155.0'
Center of turbines
-165.0'
-193.0'
35.0' 7.0' 28.0'
52.5'
70.0'
Powerhouse
Draft tunnel
Plan EL. -125.0'
Access tunnel
20.0'
186.0'
Erction bay
-125.0'
A
70.0'
32.0'
7.0'
25.0'
3.0'
80.5'
50.0'
15.0'
Draft gate
Transformer
20.0'
3.0'
90.0'
10.0'
Section C – C
-72.7'
-90.0'
50.0'R
60.0'R
Transformer
-125.0'
3.0' 32.0' 32.0' 3.0'
70.0'
Scale 1:400
REVISIONS
REFERENCE DRAWINGS
Okahara & Associates Inc.
CONSULTING ENGINEERS
FIGURE III-8
DRAWING NO.
SHEET NO.
REVISION



REVISIONS

REFERENCE DRAWINGS

Okahara & Associates Inc.

CONSULTING ENGINEERS

FIGURE III–9

DRAWING NO

SHEET NO

REVISION

6

D. KAAU CRATER PUMPED STORAGE POWER PROJECT

Kaau Crater, the upper reservoir site, is located inland at the upper end of Palolo Valley on Oahu; the lower reservoir site is in Maunawili Valley about 1 mile north of the Kaau Crater, as shown on Figure III-3.

The tunnels and powerhouse of the project will be located underground to ensure the existing natural condition be retained, and emphasis will also be placed on minimizing the effects of noise and vibration.

However, an access road of about 3.5 miles long should be provided from the Palolo Valley side to the upper reservoir, which will serve for transportation of materials and facilities during construction as well as maintenance of the upper reservoir. In addition, it would take six months from December to May in the average year to impound the lower reservoir, on the assumption that the downstream requirement of Maunawili Valley could be met by the release of 311.8 x 10^6 gallons after impounding 531.2 x 10^6 gallons of water in the reservoir. Discharge data are shown on Table III - A and III - B.

Preliminary plans and profiles of the Kaau Crater Pumped Storage Project showing the major project components are provided on Figures III - 10 to III 14. Principal features of major project components of the proposed hydroelectric facility are shown in the following:

Principal features of major project components

Upper Reservoir		
Maximum water level	feet	1,560
Minimum water level	feet	1,520
Reservoir bottom elevation	feet	1,500
Water surface area at Max. water level	acre	34
Water surface area at Min. water level	acre	22
Total storage at Max water level	ac-ft	1,350
Effective storage	ac-ft	1,130
Available drawdown	feet	40
Lower Reservoir		
Maximum water level	feet	550
Minimum water level	feet	500
Reservoir bottom elevation	feet	460
Water surface area at Max. water level	acre	30
Water surface area at Min. water level	acre	15
Total storage at Max. water level	ac-ft	1,470
Effective storage	ac-ft	1,130
Available drawdown	feet	50
Dam		
Upper Reservoir Dam		
Dam Type	Fill dam with rubber liner	
Dam crest elevation	feet	1,570
Dam height	feet	70
Crest length	feet	600
Lower Reservoir Dam		
Dam Type	Fill dam with rubber liner	
Dam Crest	feet	560
Dam Height	feet	140
Crest length	feet	1,700
Gross head		
Maximum	feet	1,060
Minimum	feet	970
Average	feet	1,015

Design Discharge (Max.)		
Generating mode	cfs	2,190
Pumping mode	cfs	1,660
Head loss		
Generating mode	feet	30
Pumping mode	feet	20
Effective heads		
Generating at avg. head	feet	985
Max. pumping height	feet	1,080
Generating power (Max.)	kW	160,000
Generating power (Avg.)	kW	160,000
Pumping power (Max.)	kW	162,000
Installed capacity	MW	160
Number of units	unit	2
Hours of generation	hr	6
Hours of storage	hr	8
Energy storage	MWh	960
Intake-Outlet	Concrete structure of Morning-glory type	
Headrace tunnel		
Length	feet	2,310
Diameter	feet	14
Area	sq. ft.	153.9
Surge-tank	Concrete structure of restricted-orifice type	
Penstock Tunnel		
Length	feet	1,430
Diameter	feet	14 - 6
Area	sq. ft.	153.9 - 28.3
Bifurcation		1
Powerhouse		
Type	Underground	
Center of turbines	ft (elev.)	320
Turbine	Vertical type Francis Reversible Pump-Turbine	

Draft Tunnel		
Length	feet	170
Line	No.	2
Tailrace tunnel		
Length	feet	2,090
Line	No.	1
Diameter	feet	14
Area	sq. ft.	153.9
Out-Inlet	Concrete structure of Inclined type	
Design seismic intensity	0.15 g	

Kaau Crater reservoir

Kaau Crater would serve as the upper reservoir for the pumped storage facility. The reservoir would be formed by constructing a small fill dam across the southeast portion of the crater rim, and excavating the surface layer of silt and clay in the floor of the crater. The crest of the dam would be at an elevation of 1,570 feet, and the dam would have a maximum height of approximately 70 feet. The reservoir would be lined with a rubber sheet to conserve water. The runoff surface water in the basin is to be caught in the side gutter of the inspection road and not allowed to flow into the reservoir. Infiltration water and leaked water from the reservoir are to be collected through the inspection gallery and returned to the reservoir by pump. A spillway would not be necessary in the upper reservoir of this type of pump-storage project.

The minimum and maximum operating levels for the reservoir would be 1,520 feet and 1,560 feet, respectively. The active storage capacity would be about 1,130 acre-feet.

A reinforced concrete inlet/outlet structure would be constructed within the crater to direct generation and pumpback flows between the reservoir and the low pressure tunnel. The structure is to be of the morning glory type, of diameter approximately 50 feet and height 20 feet for the maximum hydraulic capacity of the project in generating and pumping modes.

Maunawili reservoir

A lower reservoir would be constructed within the Maunawili Valley just north of the Koolau Range escarpment and Mt. Olympus. The reservoir would be formed by constructing a fill-type dam with a crest length of about 1,700 feet and a maximum height of about 140 feet, and improving the present topography by excavation and embankment. The reservoir would be lined with a rubber sheet to conserve water. The crest of the dam would be at an elevation of 560 feet. The minimum and maximum operating levels for the reservoir would be 500 feet and 550 feet, respectively. The active storage capacity would be 1,130 acre-feet, corresponding to the active capacity of Kaau Crater Reservoir.

A reinforced concrete inlet/outlet structure of inclined type would be constructed within the lower reservoir to direct generation and pumpback flows between the reservoir and the tailrace tunnel. The inlet/outlet structure would be designed for the maximum hydraulic capacity of the pumped storage project in both generating and pumping modes.

A small dam of crest length approximately 400 feet is to be provided in a stream approximately 2,500 feet south of the reservoir, and an auxiliary regulating pond is to be made connecting to the reservoir with a horizontal tunnel, or water supply and drainage tunnel of 10 feet in diameter. It will serve to increase the catchment area of the reservoir during initial water impounding, and be converted to an uncontrolled overflow spillway tunnel to pass the discharge in the event of overfilling during the power plant operation.

The inflow water from the basin of the reservoir is to be caught in the side gutter of the inspection road and is to be run down by a shaft to the drainage tunnel.

Powerhouse

The powerhouse is located in the Koolau basalt zone. It would be concrete-lined of an underground type sized to accommodate two vertical, reversible pump/turbines directly coupled to motor/generators. The powerhouse also would have sufficient space for an equipment laydown area for maintenance purposes and for the auxiliary mechanical and electrical equipment. The unit set-up transformer would be located beside the equipment laydown area. The setting level of the pump/turbine distributors would be 180 feet below the minimum operating level within the lower reservoir to provide the submergence depth required for pumpback operations.

Access to the powerhouse would be by an access tunnel approximately 0.60 miles in length from the lower reservoir site, and a power cable tunnel will be provided between the powerhouse and the plant substation, which is sited in the western area of the lower reservoir at an elevation of approximately 600 feet. A drainage tunnel would be provided around the powerhouse cavern in order to reduce the leakage of water to the cavern by means of grout curtains and drain holes.

Water conductors

The water conductors would include headrace and tailrace systems. The headrace system would extend from the Kaau Crater inlet/ outlet structure to the powerhouse to convey generation and pumpback flows between Kaau Crater Reservoir and the hydroelectric units. The headrace system would consist of a low pressure tunnel, a inclined penstock and individual unit penstocks.

The low pressure tunnel would extend with an 8.3 percent downward slope from the Kaau Crater inlet/ outlet structure for a distance of 2,260 feet to the intersection with the inclined penstock. The penstock would then extend downward with an angle of 48 deg. for a distance of about 1,290 feet, where individual penstocks would convey discharges to each unit. The penstock and low pressure tunnel would have a finished inside diameter of approximately 14 feet on the average and either would be lined with concrete or concrete encased steel. The individual unit penstocks would be approximately 10 feet in diameter on the average and would have concrete encased steel liners.

The tailrace tunnel would extend from the unit draft tubes to the lower reservoir inlet/outlet structure to convey generation and pumpback flows between the powerhouse and the lower reservoir. The tailrace tunnel would be approximately 1,920 feet in length and would have a finished inside diameter of 14 feet. The tailrace tunnel would be concrete lined.

A headrace surge tank of restricted orifice type with inside diameter of 24 feet is to be provided at a location 2,180 feet in horizontal distance from the intake, and another surge tank of the same scale (inside diameter 24 feet) as the headrace is to be provided at a location 350 feet from the turbine center in the tailrace tunnel. These features will release the water hammer pressure and regulate the water discharge in the tunnel according to the change of load.

Pump/turbine - Motor/generators

Two vertical, single stage, Francis reversible pump/turbine units of 80 MW each would pump water and generate electricity. The pump/turbines would be directly coupled to vertical shaft, three-phase, 60 hertz, ac synchronous motor/generators.

Substation/transmission line

The plant substation would be located at ground level adjacent to the power cable tunnel portal just west of the lower reservoir in Maunawili, however, the unit step-up transformers could be located in an underground cavern. A 138 kV transmission line would extend from the plant substation to the interconnection with an existing HECO 138 kV transmission line which is located nearby.

Project operations

The project would be operated as a conventional pumped storage hydroelectric facility with the generation cycle occurring during on-peak electrical demand periods and the pumpback cycle occurring during off-peak periods. The normal daily operating cycle would begin with Kaau Crater Reservoir at maximum operating level and the lower reservoir at minimum operating level. During the on-peak generation cycle, the hydro units would function as turbine-generators, and water would be conveyed from the Kaau

Crater Reservoir to the lower reservoir through the pump-turbines and water conductor system. During the off-peak pumpback cycle, the units would function as pump-motors, and water would be conveyed from the lower reservoir to Kaau Crater Reservoir.

During the daily generating cycle, average plant output would be 160 MW for a period of six hours. During the pumpback cycle, an average of approximately 162 MW plant input would be required for a period of about eight hours to refill Kaau Crater Reservoir. Cycle efficiency is expected to be about 75 percent.

Operation

The PSH facility is proposed to be operated from the switchyard and will have a staff of 15 people to provide operation and maintenance (i.e. 24 hour, 7 days a week).

Kaau Crater Pumped Storage Power Project
Maunawili Monthly Discharge
Water impounding period: 6 months (December to May)

	Station No. 16254000 Drainage area 2.04 $mile^2$ (A)	Proposed Maunawili dam site 1.29 $mile^2$ (B)	Proposed Maunawili dam site 1.29 $mile^2$ (C)	Proposed Maunawili dam site 1.29 $mile^2$ (D)	Proposed Maunawili water impounding (E)	Downstream release (A) - (E)	Downstream release (A) - (E)
	cf/s	cf/s	acre-feet	x 10^6 gallon	acre-feet	cf/s	x 10^6 gallon
October	92.4	58.2	115.4	37.5	-	92.4	59.5
November	166.9	105.1	208.4	67.7	-	166.9	107.4
December	219.6	138.3	274.3	89.0	274.3	81.3	52.3
January	253.6	159.8	316.9	102.9	316.9	93.8	60.4
February	215.2	135.6	268.9	87.3	268.9	79.6	51.2
March	241.9	152.4	302.3	98.1	302.3	89.5	57.6
April	209.8	132.2	262.2	85.1	262.2	77.6	49.9
May	169.7	106.9	212.0	68.8	212.0	62.8	40.4
June	101.8	64.1	127.1	41.3	-	101.8	65.5
July	82.2	51.8	102.7	33.3	-	82.2	52.9
August	75.3	47.5	94.2	30.6	-	75.3	48.5
September	64.8	40.8	89.9	26.3	-	64.8	41.7
	1,893.2 (1,218.6 x 10^6 gallon)	1,192.7	2,374.3	767.9	1,636.6	1,068.0	687.3

- Adjusted annual evaporation at Station No. 787.10 (1976 - 84):
  49.8 = 50 inch/year (4.17 feet/year)

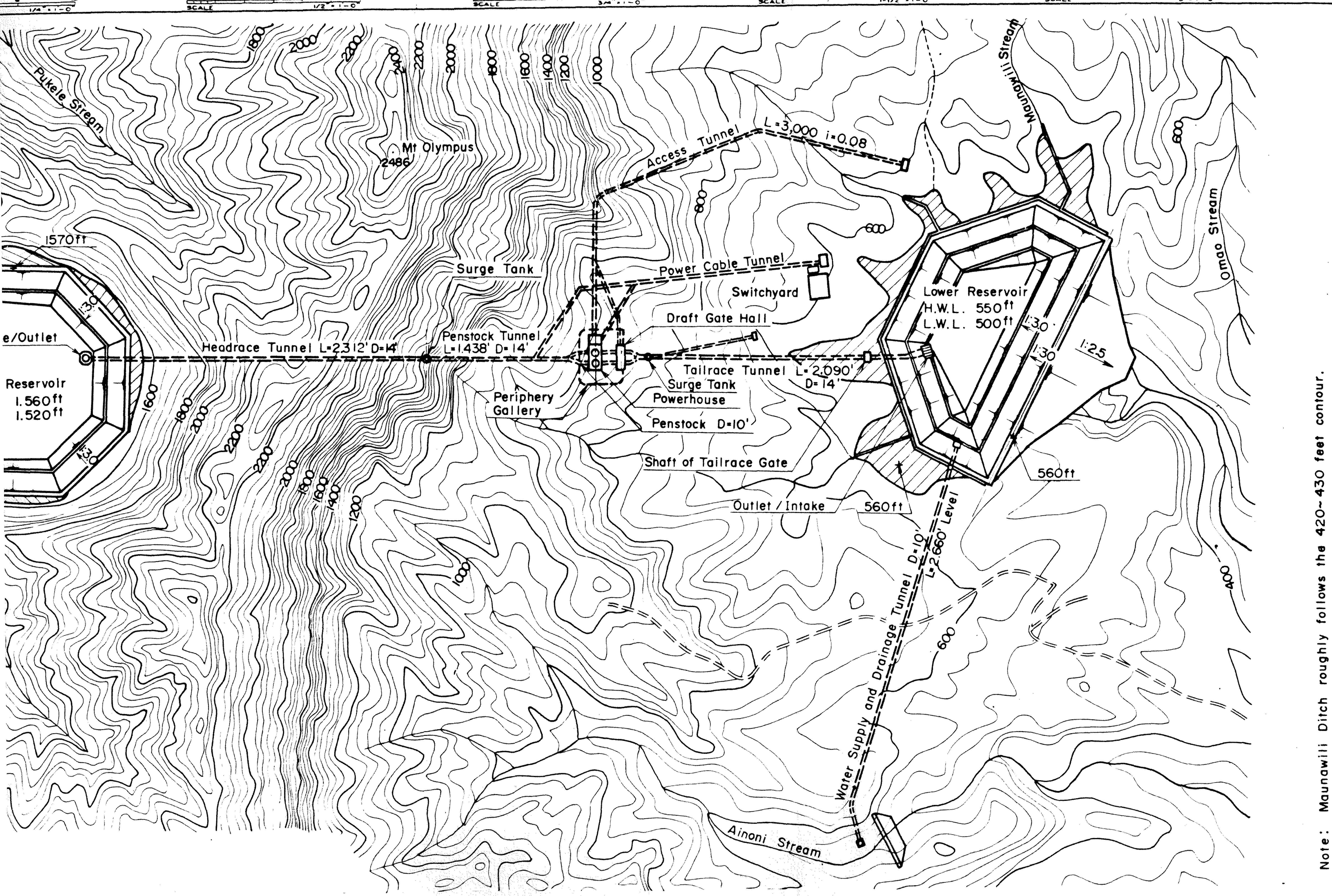
- Evaporation at lower reservoir
  {4.17 feet/year x 1/2 = 2.09 feet/6 month} x 25 acre = 52.3 acre-feet

- Lower reservoir water impounding capacity: 1,470 + 52.3 acre-feet = 1,522.3 acre-feet

STATION NO. 16254000, MAKAWAO STREAM NEAR KAILUA, OAHU, HI STREAM SOURCE AGENCY USGS
LATITUDE 212149, LONGITUDE 1574602, DRAINAGE AREA 2.04, DATUM 80.00, STATE 15, COUNTY 003,
DISCHARGE, CUBIC FEET PER SECOND, MONTHLY TOTAL OF DAILY MEAN VALUES

No.	Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
1	1958 - 1959	172.2	142.6	113.4	241.1	140.9	78.4	67.9	49.4	41.9	38.9	83.3	50.2
2	1959 - 1960	42.8	57.6	63.2	66.6	94.9	554.5	144.3	129.6	70.3	62.9	46.6	40.6
3	1960 - 1961	62.6	44.4	86.5	242.5	172.1	109.3	86.8	56.1	46.9	45.6	37.2	33.5
4	1961 - 1962	74.8	248.5	142.3	132.9	162.1	289.5	139.8	233.2	69.3	55.5	45.4	40.1
5	1962 - 1963	38.6	29.8	75.2	343.2	221.5	670.3	941.5	508.4	193.6	122.7	81.8	68.2
6	1963 - 1964	70.5	59.8	168.0	198.8	89.9	242.3	157.6	99.8	72.4	97.9	73.6	32.8
7	1964 - 1965	116.3	207.3	476.0	233.7	502.7	225.0	271.8	457.2	169.3	137.3	78.7	77.3
8	1965 - 1966	261.4	1,145.6	549.9	303.3	377.1	231.6	157.0	154.8	86.1	85.1	76.6	66.7
9	1966 - 1967	151.3	291.1	203.9	196.6	163.7	348.3	223.8	183.4	109.0	120.0	211.3	192.0
10	1967 - 1968	151.3	136.7	828.8	394.2	256.6	680.7	682.2	185.1	109.2	86.1	70.9	67.0
11	1968 - 1969	73.9	103.8	354.6	437.7	529.1	457.2	203.3	142.0	97.6	103.1	74.5	75.0
12	1969 - 1970	67.6	72.9	129.9	355.6	117.9	81.3	83.8	74.7	60.8	60.6	51.7	47.4
13	1970 - 1971	69.6	453.9	240.5	378.9	249.1	120.8	206.0	121.9	115.6	75.0	55.9	48.0
14	1971 - 1972	46.0	47.9	76.7	255.7	227.0	229.1	256.7	104.7	68.7	54.1	45.6	35.6
15	1972 - 1973	35.5	34.5	38.0	38.4	49.0	44.6	46.4	43.3	34.5	47.3	36.9	31.3
16	1973 - 1974	36.5	64.6	144.2	314.6	276.7	151.0	117.9	109.7	74.2	55.8	47.5	40.5
17	1974 - 1975	54.0	100.9	61.9	220.3	336.8	119.2	94.2	67.5	51.8	46.2	38.5	30.1
18	1975 - 1976	32.8	149.2	66.2	48.7	114.1	218.4	88.9	73.8	53.8	49.7	41.5	42.3
19	1976 - 1977	67.3	46.1	40.8	38.8	34.2	45.7	170.2	337.0	86.6	59.0	48.7	39.7
20	1977 - 1978	36.2	38.5	37.9	47.1	31.2	38.7	76.4	165.8	105.1	71.9	65.8	50.0
21	1978 - 1979	167.8	282.2	223.1	373.4	760.6	248.3	120.7	86.3	61.6	52.1	46.5	37.4
22	1979 - 1980	40.9	51.8	218.9	607.9	164.2	155.0	200.7	238.4	203.4	150.7	114.5	76.4
23	1980 - 1981	64.3	63.5	168.6	126.2	119.7	81.4	122.7	534.3	111.9	67.9	81.8	52.0
24	1981 - 1982	60.5	177.2	537.3	867.0	296.6	489.1	475.0	167.3	339.0	206.6	264.0	174.8
25	1982 - 1983	180.8	184.3	254.3	169.6	114.7	93.3	79.6	85.0	70.0	70.3	60.9	60.9
26	1983 - 1984	60.7	64.2	83.6	94.3	96.7	82.1	86.8	62.9	47.8	47.0	36.6	32.3
27	1984 - 1985	33.0	61.7	97.3	123.8	436.7	118.7	81.0	75.5	60.8	57.8	55.7	57.7
28	1985 - 1986	155.1	152.8	102.8	70.1	63.5	212.3	104.1	83.0	72.6	66.4	68.0	125.0
29	1986 - 1987	122.9	396.7	158.2	156.7	158.4	107.6	107.2	146.7	110.3	127.5	77.1	76.0
30	1987 - 1988	84.8	129.9	1,077.8	884.0	323.8	270.4	186.3	385.1	106.7	76.9	103.3	63.5
31	1988 - 1989	86.4	102.7	236.3	175.5	209.4	369.8	926.1	233.3	295.7	162.5	115.4	84.0
32	1989 - 1990	131.0	79.1	83.7	223.5	194.4	365.7	164.8	130.4	93.4	85.6	78.3	68.1
33	1990 - 1991	67.2	329.2	192.9	153.0	125.8	614.2	194.5	122.9	92.1	71.1	64.5	60.2
34	1991 - 1992	224.3	121.9	135.3	107.3	104.5	80.8	68.0	121.5	80.8	77.0	81.9	125.4
	Monthly Average Total Discharge (1958 - 1992)	92.4	166.9	219.6	253.6	215.2	241.9	209.8	169.7	101.8	82.2	75.3	64.8
	Monthly total for Drainage Area of 1.29 mile^2, Area ratio 1.29/2.04 = 0.63												
	Cubic feet/sec	58.2	105.1	138.3	159.8	135.6	152.4	132.2	106.9	64.1	51.8	47.5	40.8
	Acre-feet	115.4	208.4	274.3	316.9	268.9	302.3	262.2	212.0	127.1	102.7	94.2	89.9

R = 2374.3
(Acre-feet)



Note: Maunawili Ditch roughly follows the 420~430 feet contour.

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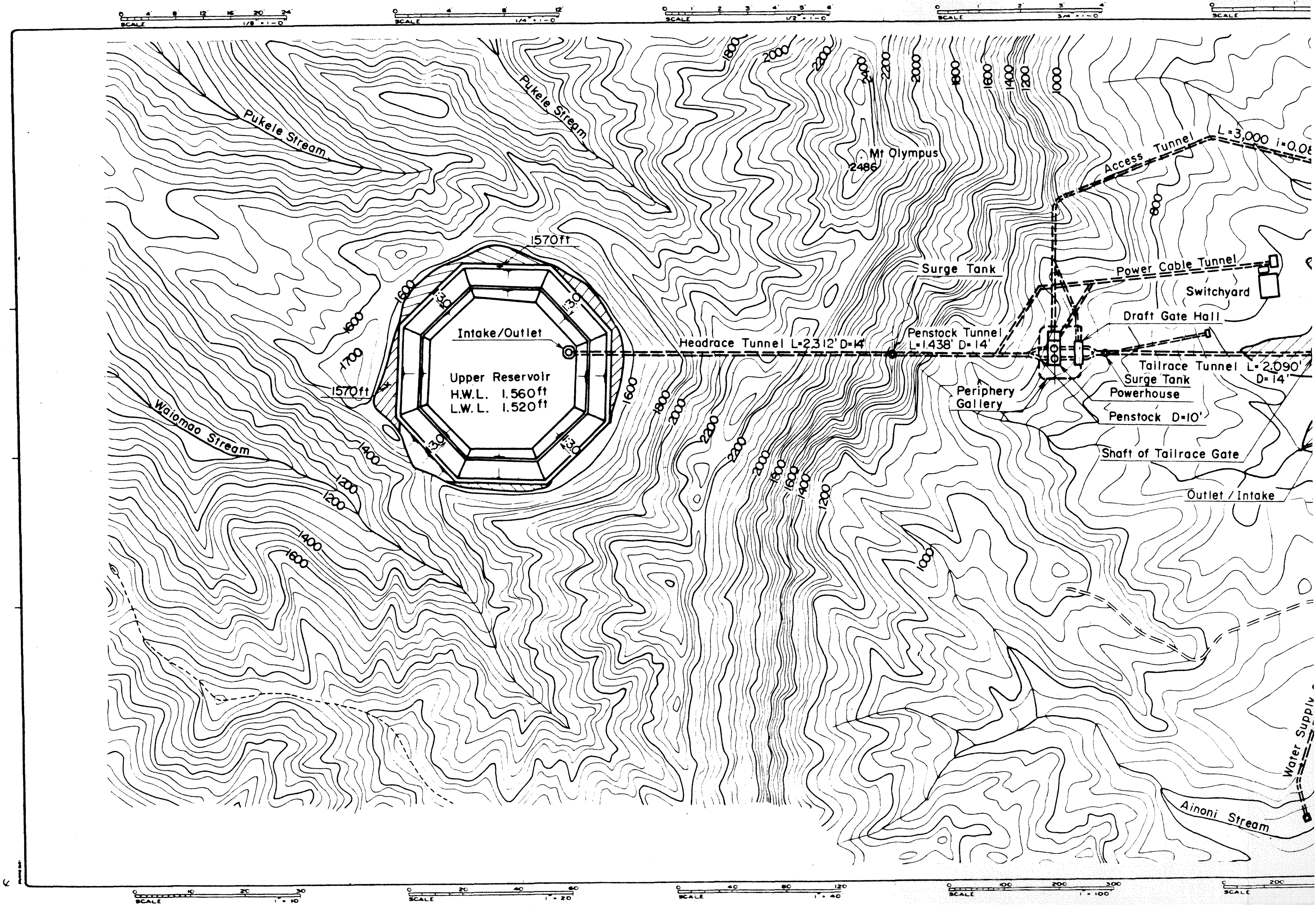
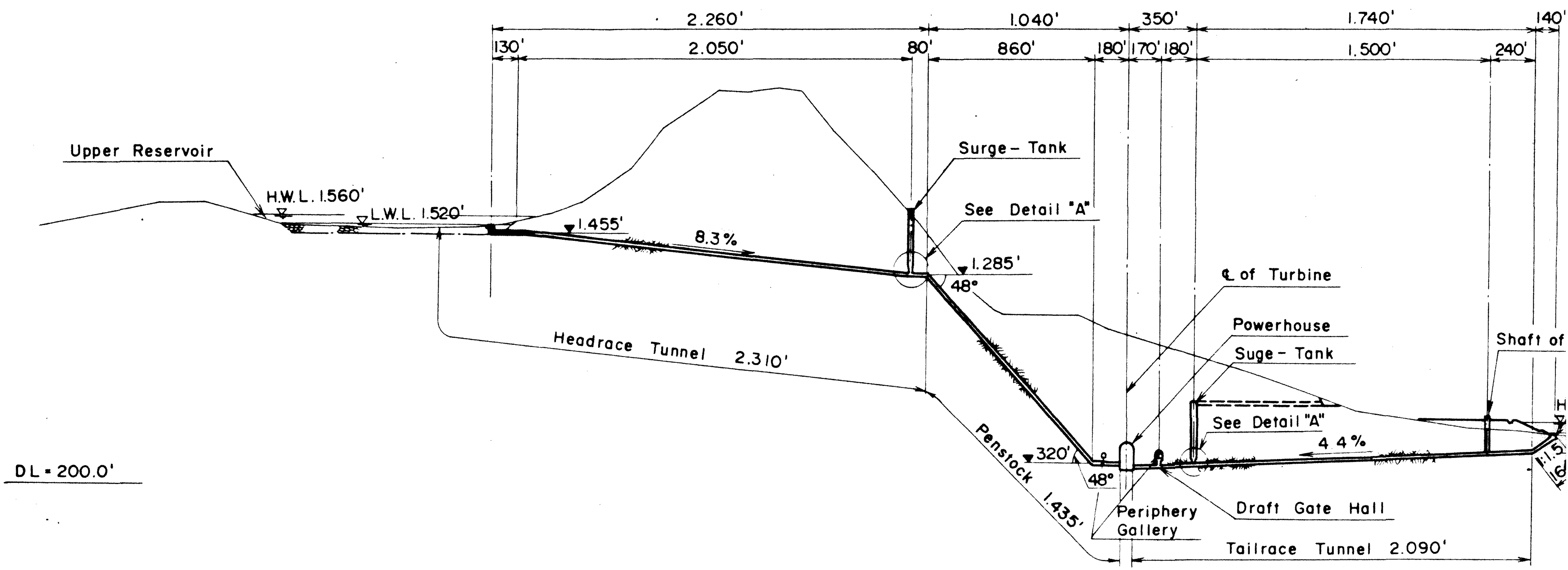
FIGURE III-10

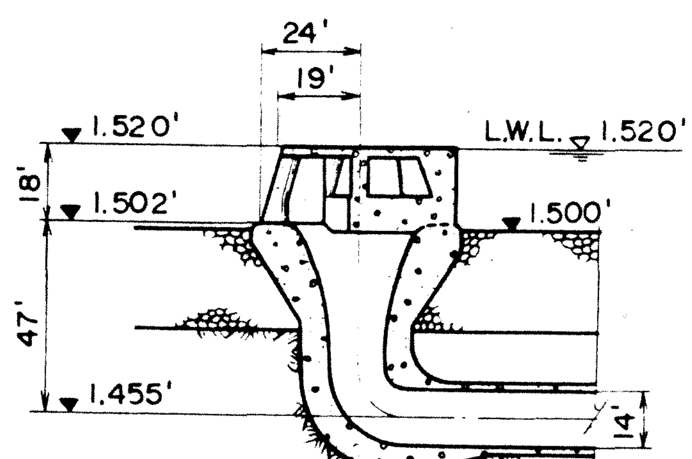


SCALE 1/8" = 1'-0
SCALE 1/4" = 1'-0
SCALE 1/2" = 1'-0
SCALE 3/4" = 1'-0
Pukele Stream
Pukele Stream
Mt Olympus
2486
Access Tunnel
L=3,000 i=0.08
Surge Tank
Power Cable Tunnel
Switchyard
Draft Gate Hall
1570ft
Intake/Outlet
Headrace Tunnel L=2,312' D=14'
Penstock Tunnel
L=1,438' D=14'
Tailrace Tunnel L=2,090'
D=14'
Surge Tank
Powerhouse
Penstock D=10'
Upper Reservoir
H.W.L. 1,560ft
L.W.L. 1,520ft
1570ft
Periphery
Gallery
Shaft of Tailrace Gate
Outlet / Intake
Waiomao Stream
Ainoni Stream
Water Supply
SCALE 1" = 10
SCALE 1" = 20
SCALE 1" = 40
SCALE 1" = 100

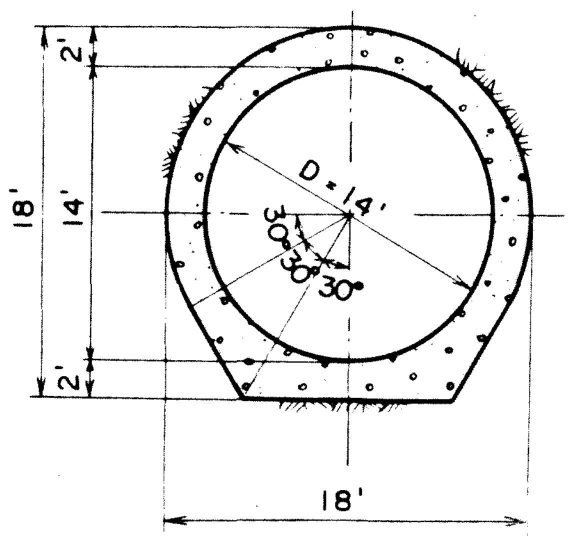
General Profile
S = 1: 6,000



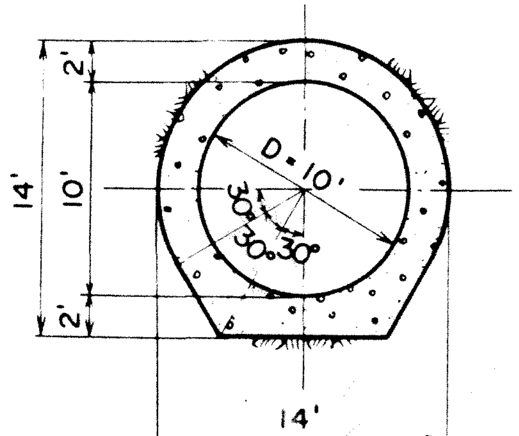
Section of Intake/Outlet
S = 500



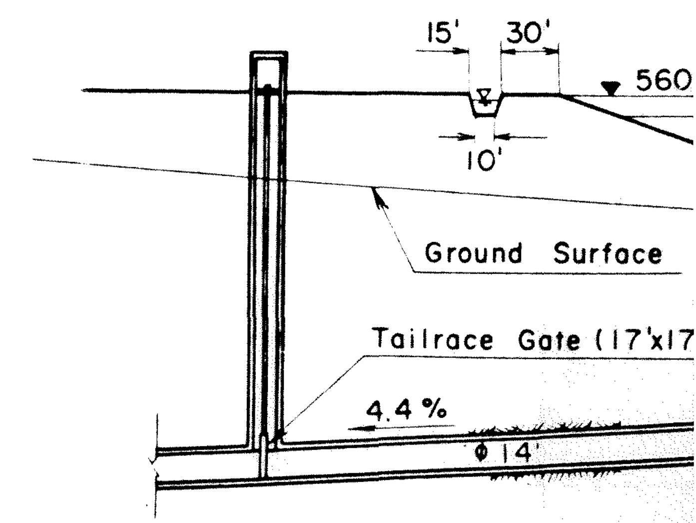
Headrace Tunnel
Tailrace Tunnel
Penstock Tunnel
S = 1:100



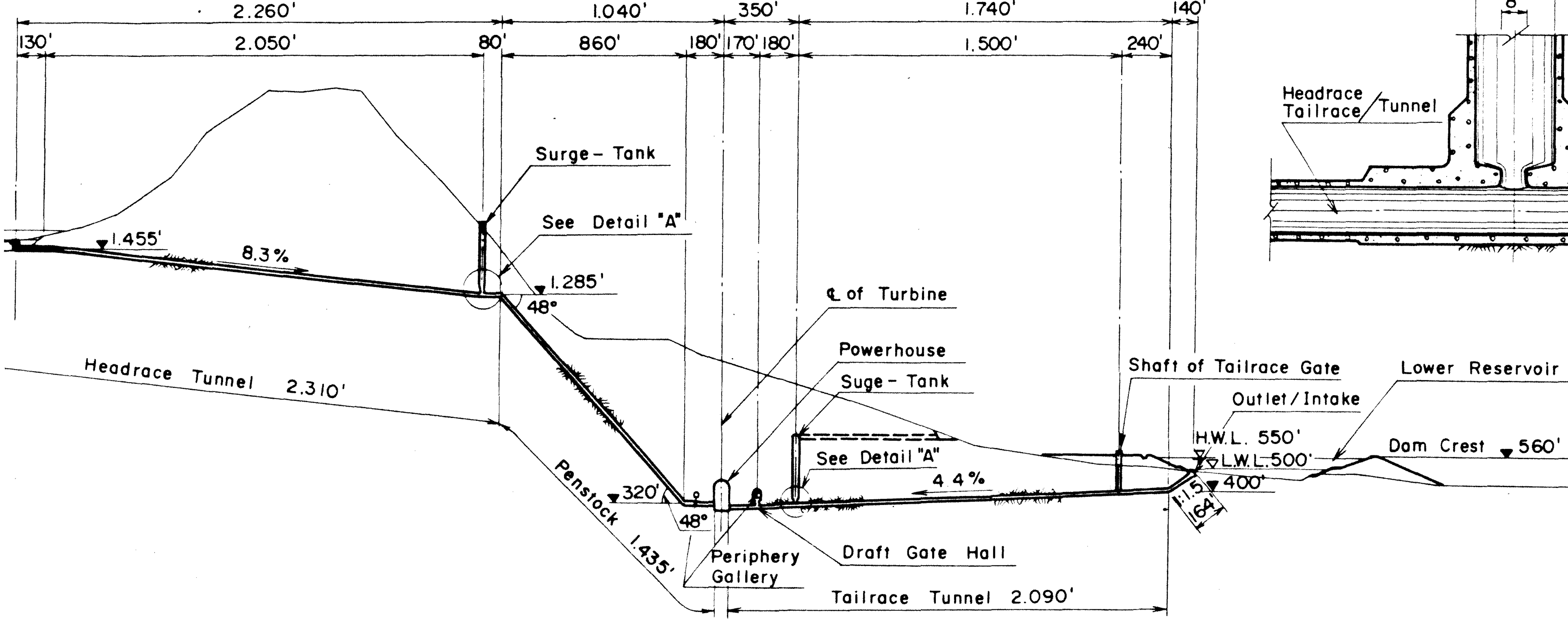
Penstock (Horizontal Area)
S = 1:100



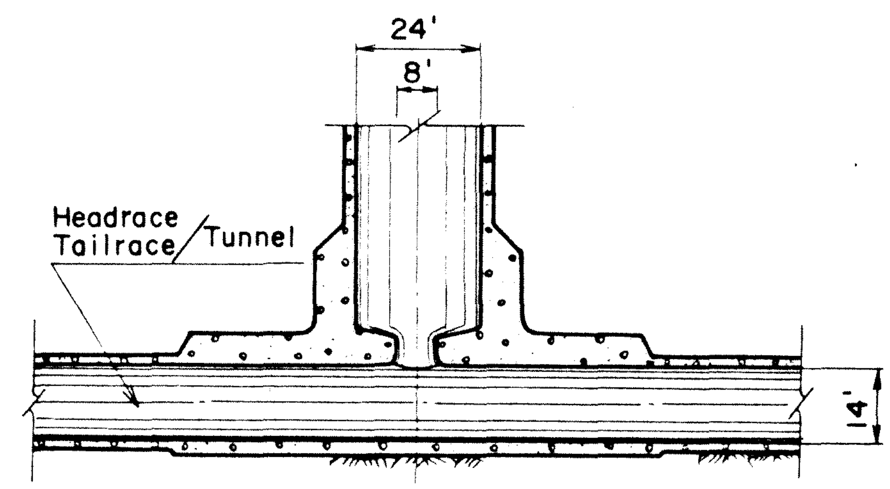
Section of Tailra



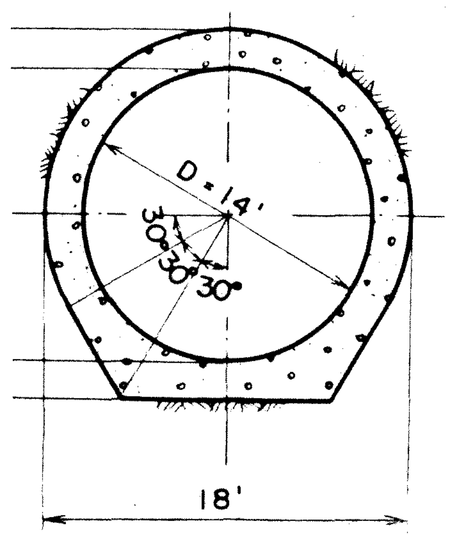
General Profile
S = 1: 6,000



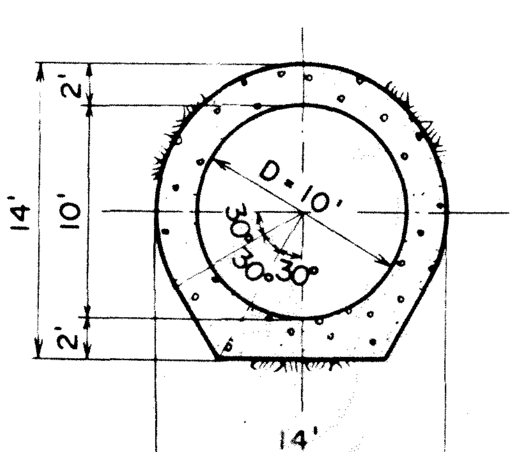
Detail "A"
S = 1:400



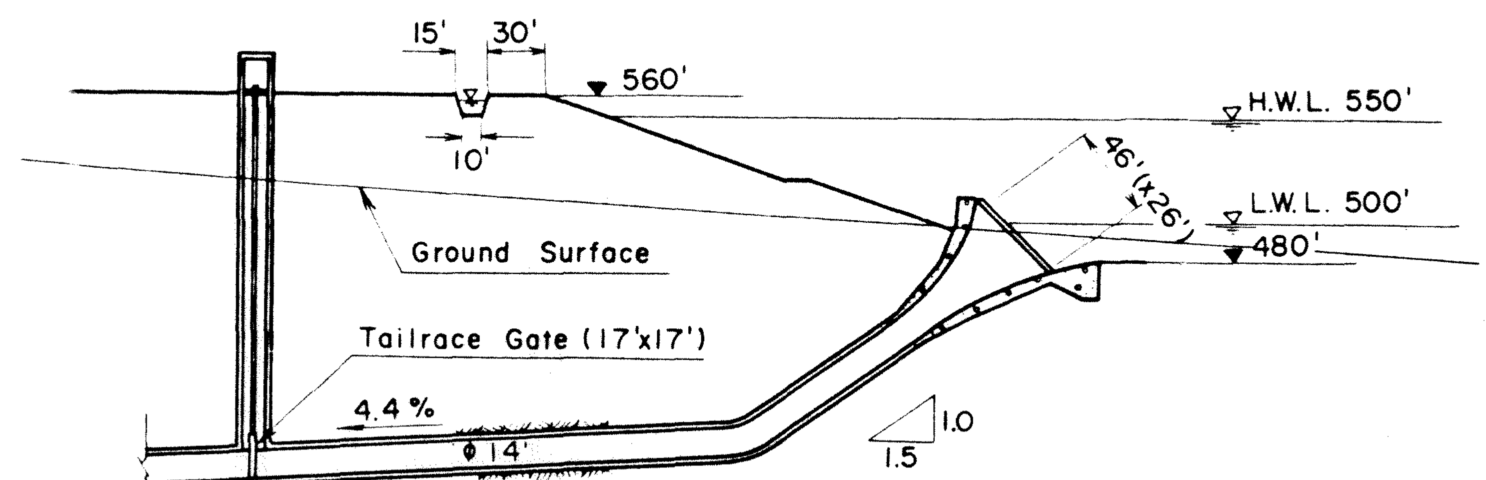
Headrace Tunnel
Tailrace Tunnel
Penstock Tunnel
S = 1:100



Penstock (Horizontal Area)
S = 1:100



Section of Tailrace Outlet
S = 1: 1,000



REVISIONS
REFERENCE DRAWINGS

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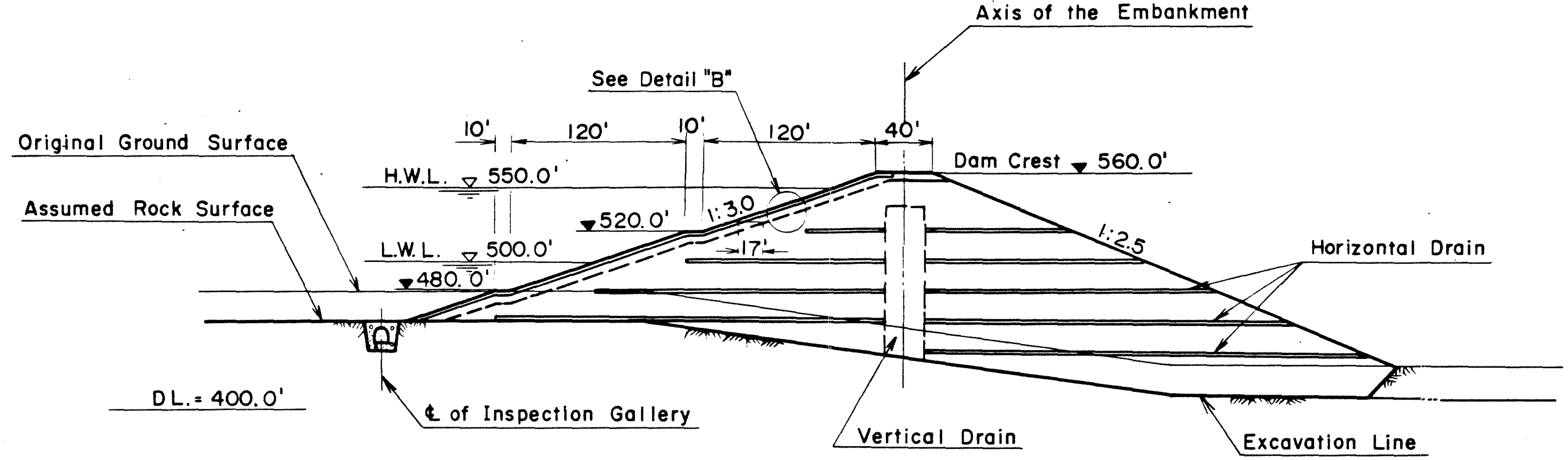
FIGURE III-11

DRAWING NO
SHEET NO
REVISION

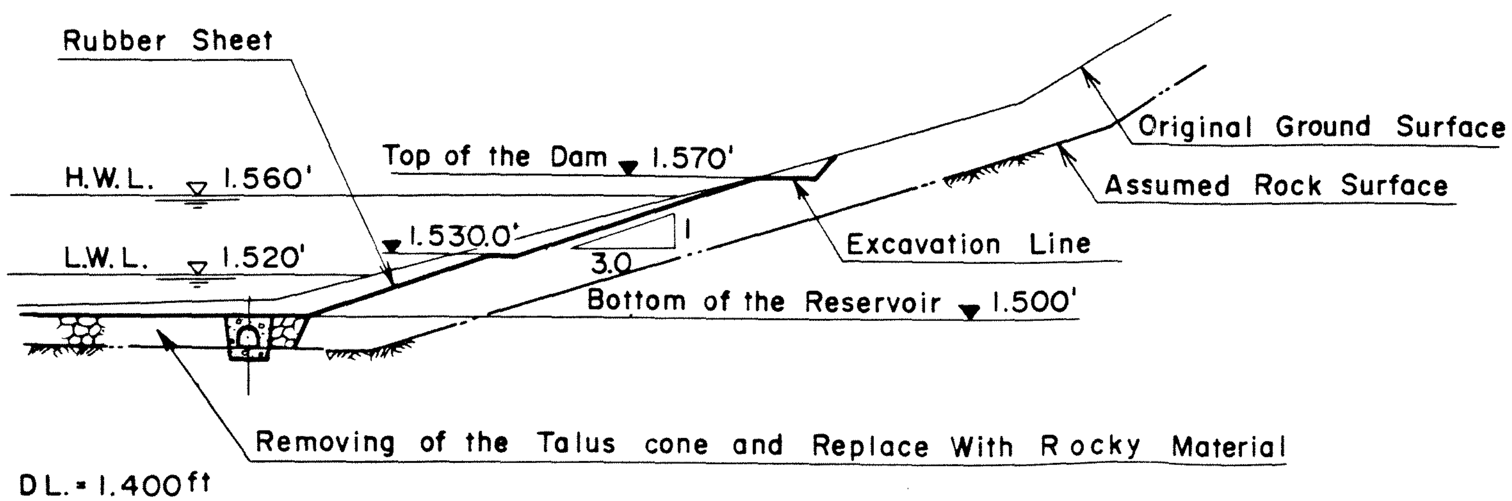
Typical Section of Lower Reservoir Dam

S = 1: 1,000



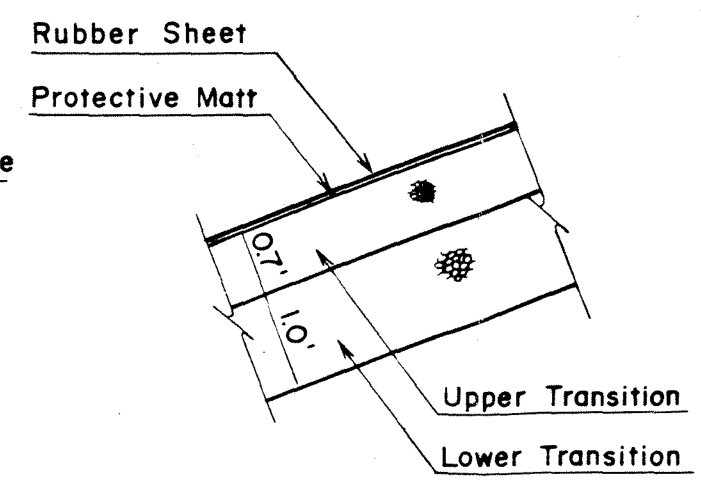
Typical Section of Upper Reservoir

S = 1: 1,000



Detail "B"

S = 1: 20



※ This detail shall be applicable to the upper reservoir of the Koko crater site.

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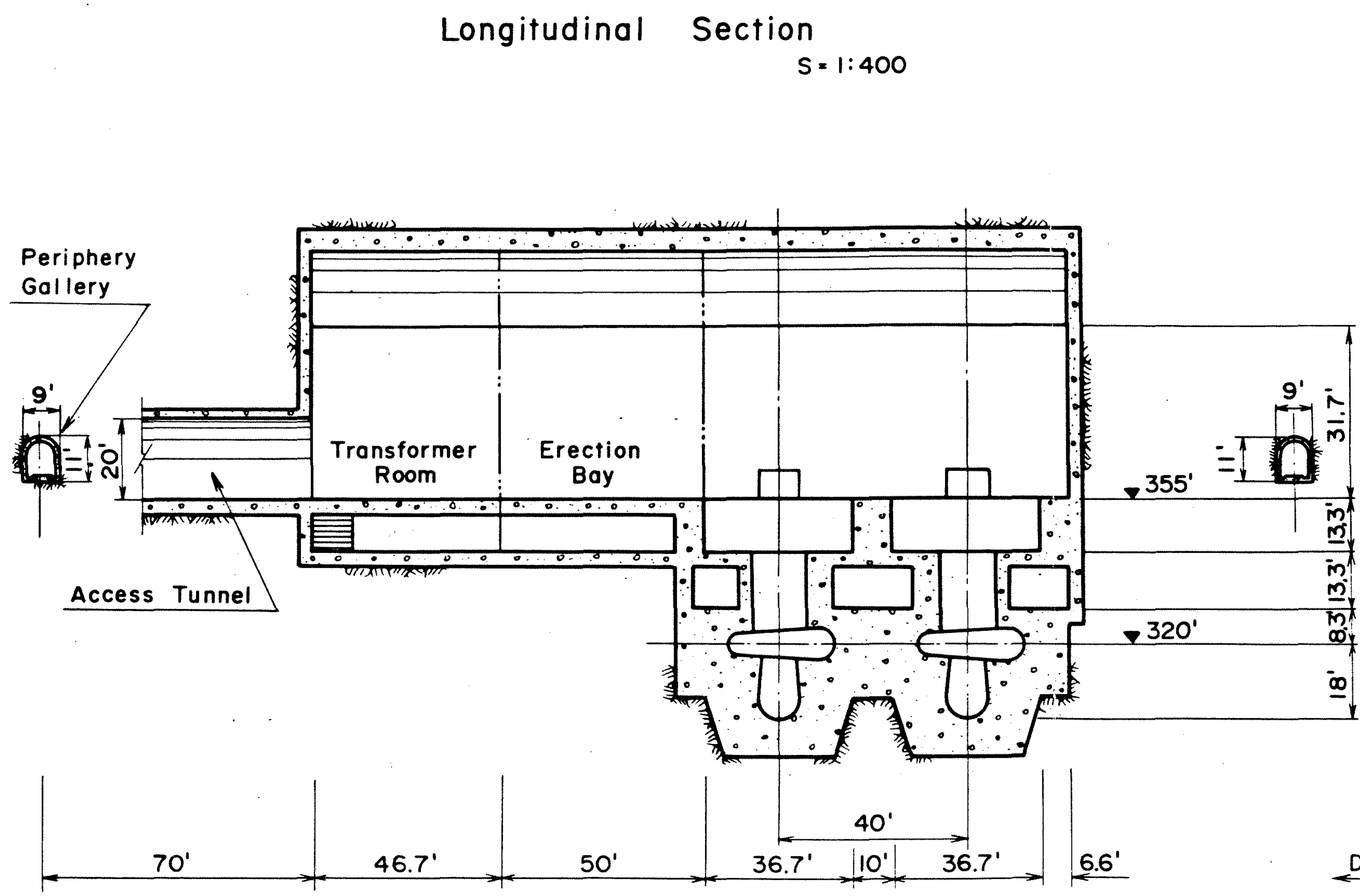
FIGURE III-12



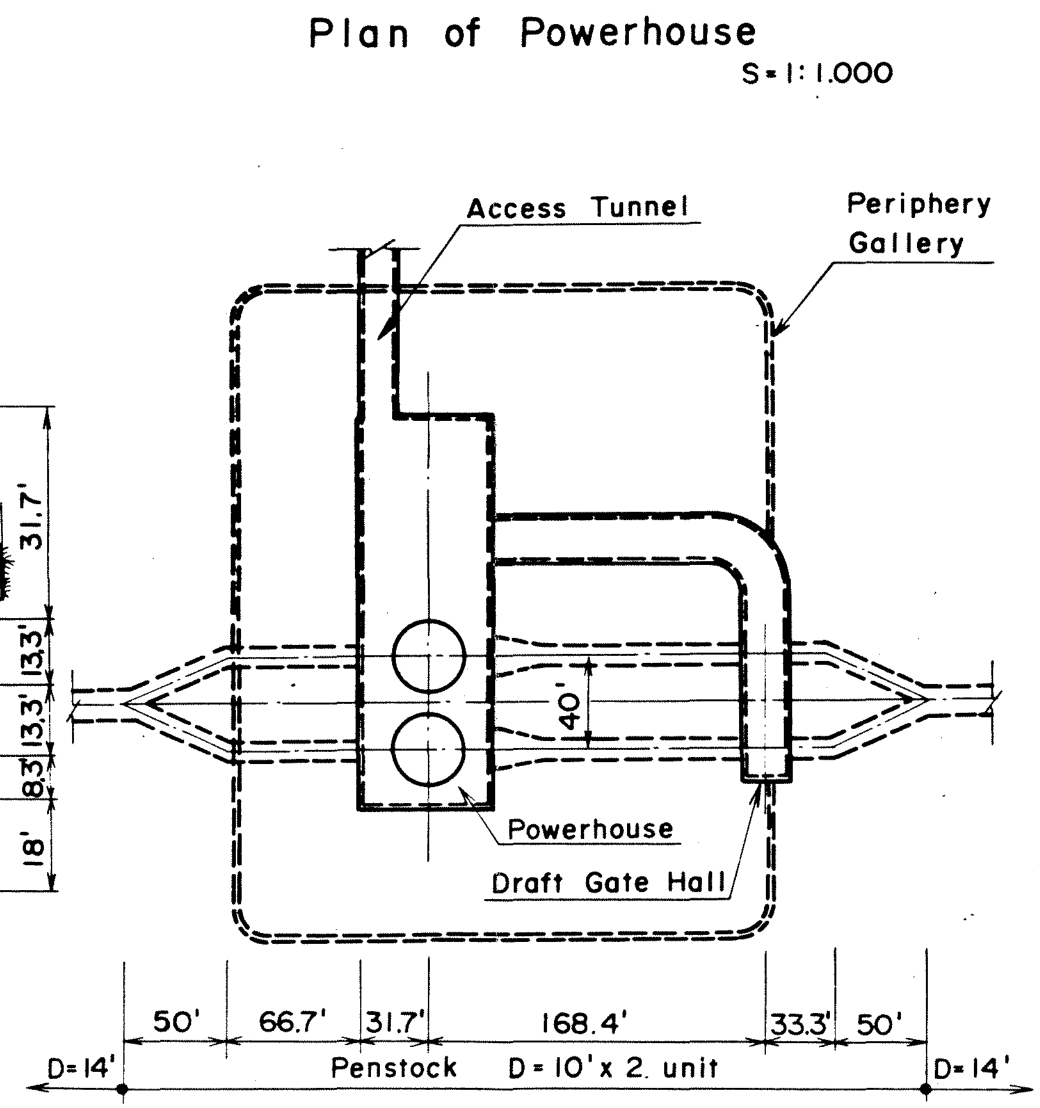


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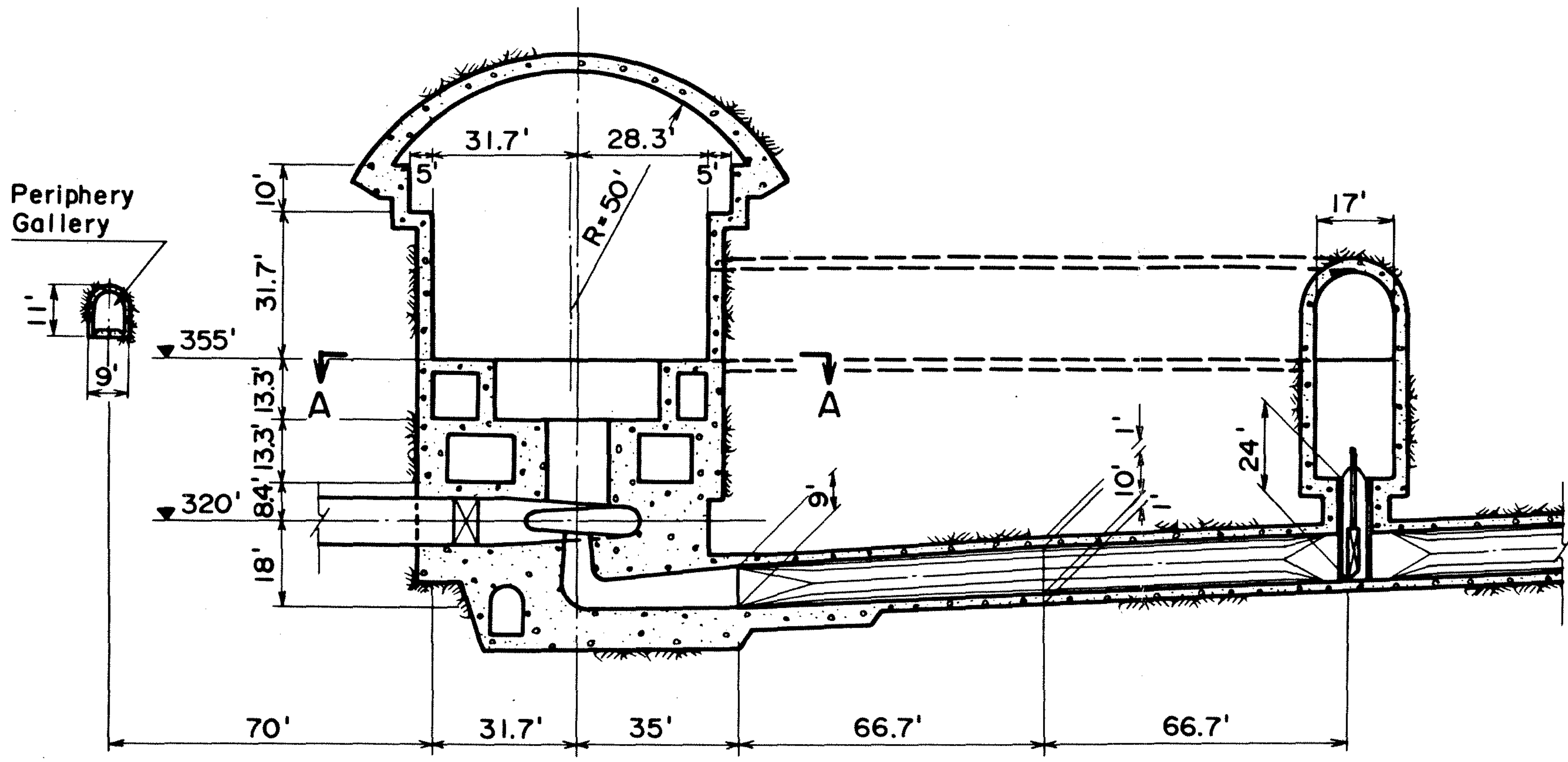
FIGURE III-13

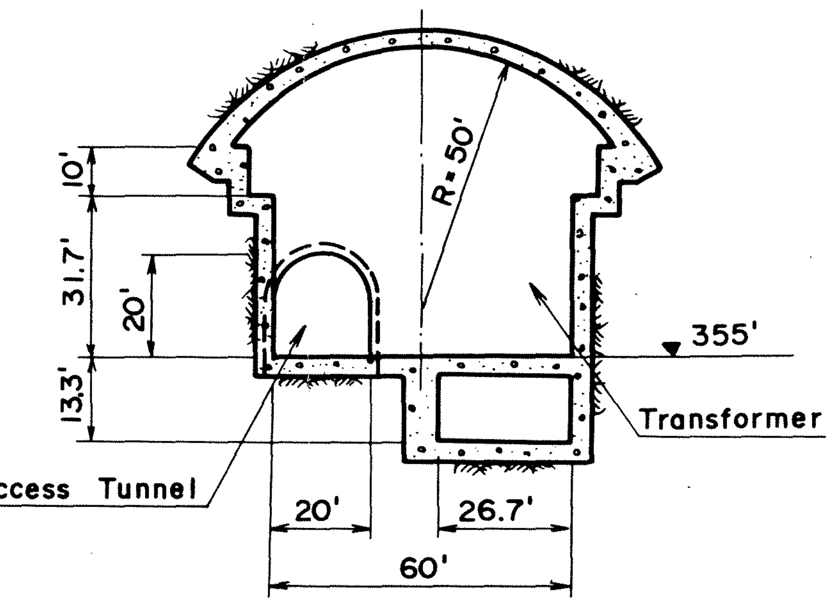
Section of Powerhouse and Draft Gate Hall

S = 1:400



Transformer Room Section B – B

S = 1:400



Powerhouse Plan A – A

S = 1:400

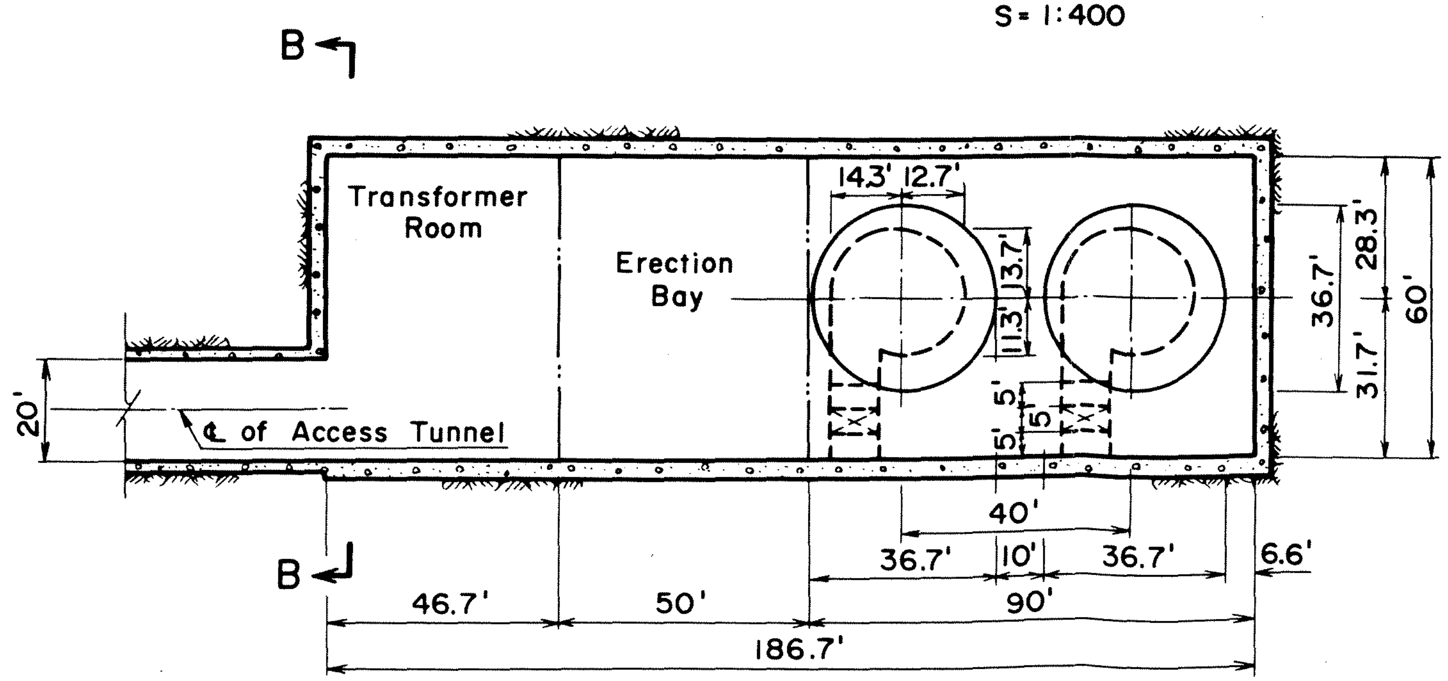


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FIGURE III-14

III E. TRANSMISSION LINES

The current electrical transmission system on Oahu consists of 138kV and 46kV overhead and transmission lines as shown on Figure III-15. Both the Koko Crater and the Kaau Crater projects will require extension of the existing transmission system and substations to interface with the power plants. The following information was developed by the Tramsmission and Distribution Planning Department of HECO.

Koko Crater: East Honolulu is currently serviced by 46kV transmission lines. This voltage level is too low to handle the 160MW of power that will be associated with Koko Crater project. This project will therefore require the installation of approximately nine miles of 138 kV transmission line extending from the existing Pukele-Koolau line to a substation in or near the new switchyard adjacent to the Hawaii Kai sewage treatment plant and a new switchyard on the Pukele-Koolau right of way. The 138kV line will be overhead (with 46kV underbuilt) where it traverses the rough mountainous terrain and mostly accessible only by helicopter. The alignment will need to be further developed before the full impact and cost of the transmission line can be determined. Figure III-16 is the proposed single line diagram for the transmission line additions.

Kaau Crater: This project will require the installation of approximately one mile of 138kV transmission line connecting from the nearby existing 138kV transmission line to the project's switchyard. The routing of the additional line will be mostly accessible by truck and will all be overhead as the existing lines are. Figures III-17 and 18 provide alternatives A and B, respectively, for the provisioning of switchyards. Alternative A provides one switchyard near the lower reservoir and close to the existing 138kV line. Alternative B provides an additional switchyard adjacent to the project's powerhouse switchyard. Additional study is required to select the more feasible alternative.

Figure

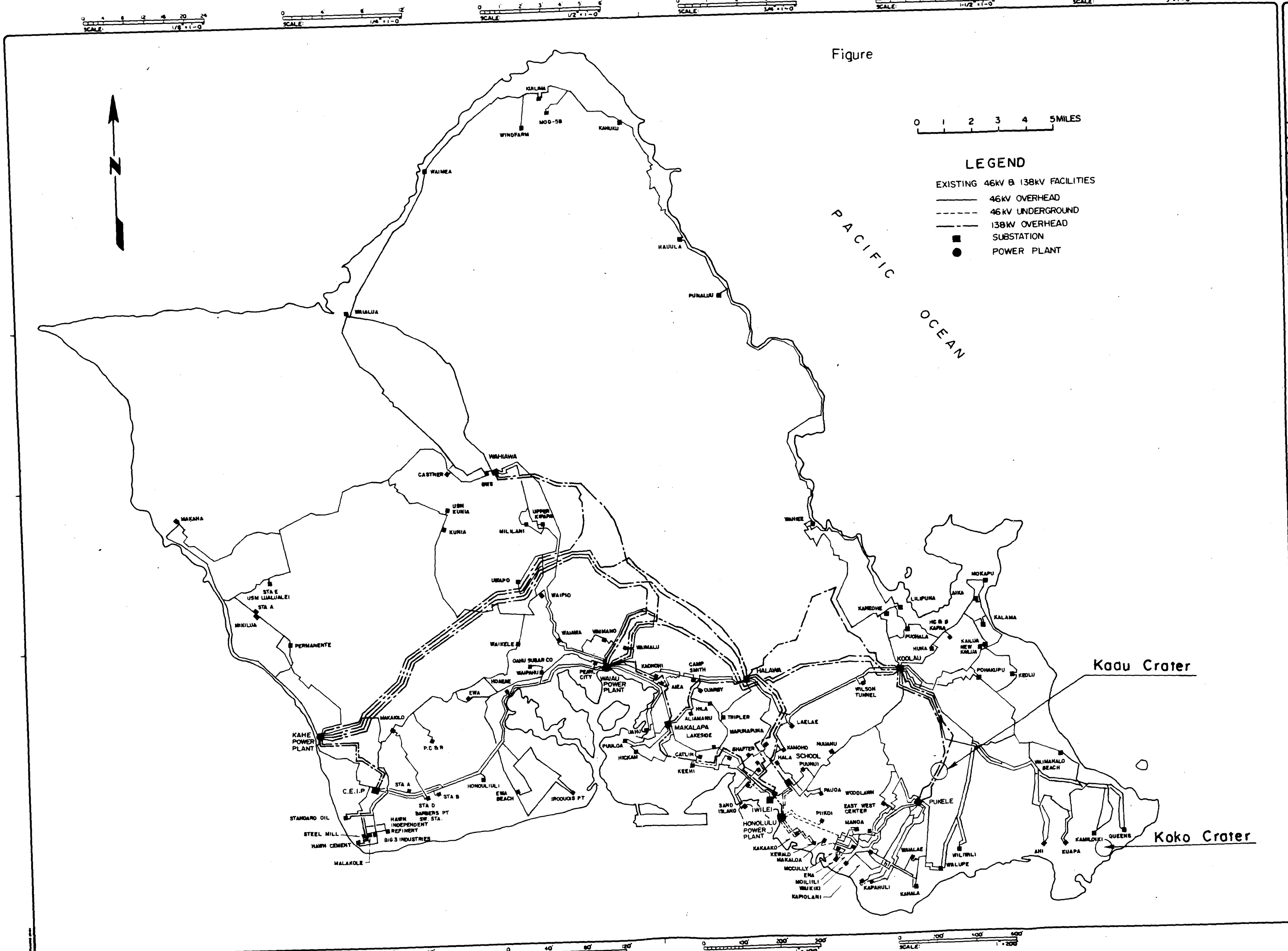

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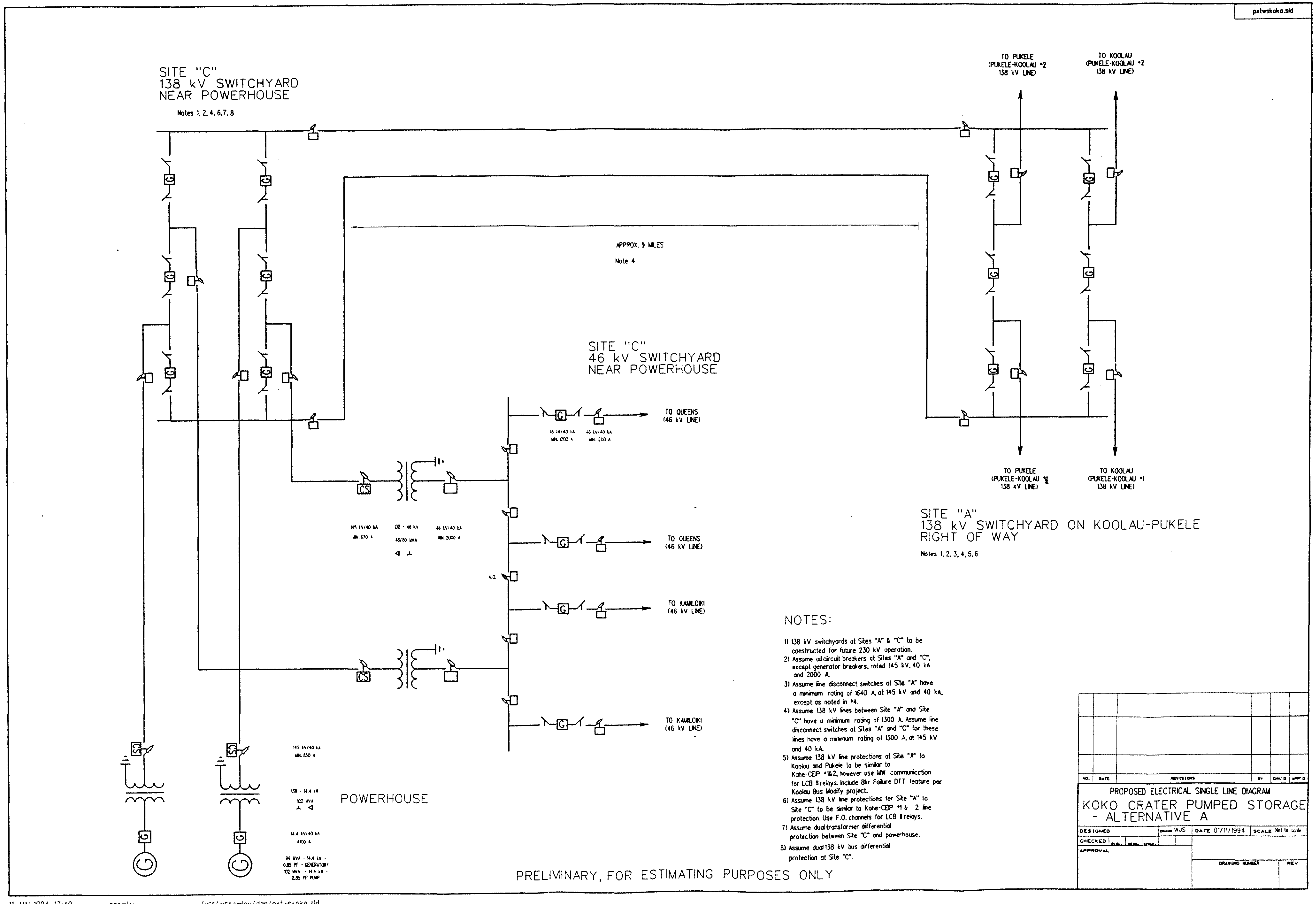
FIGURE III-15

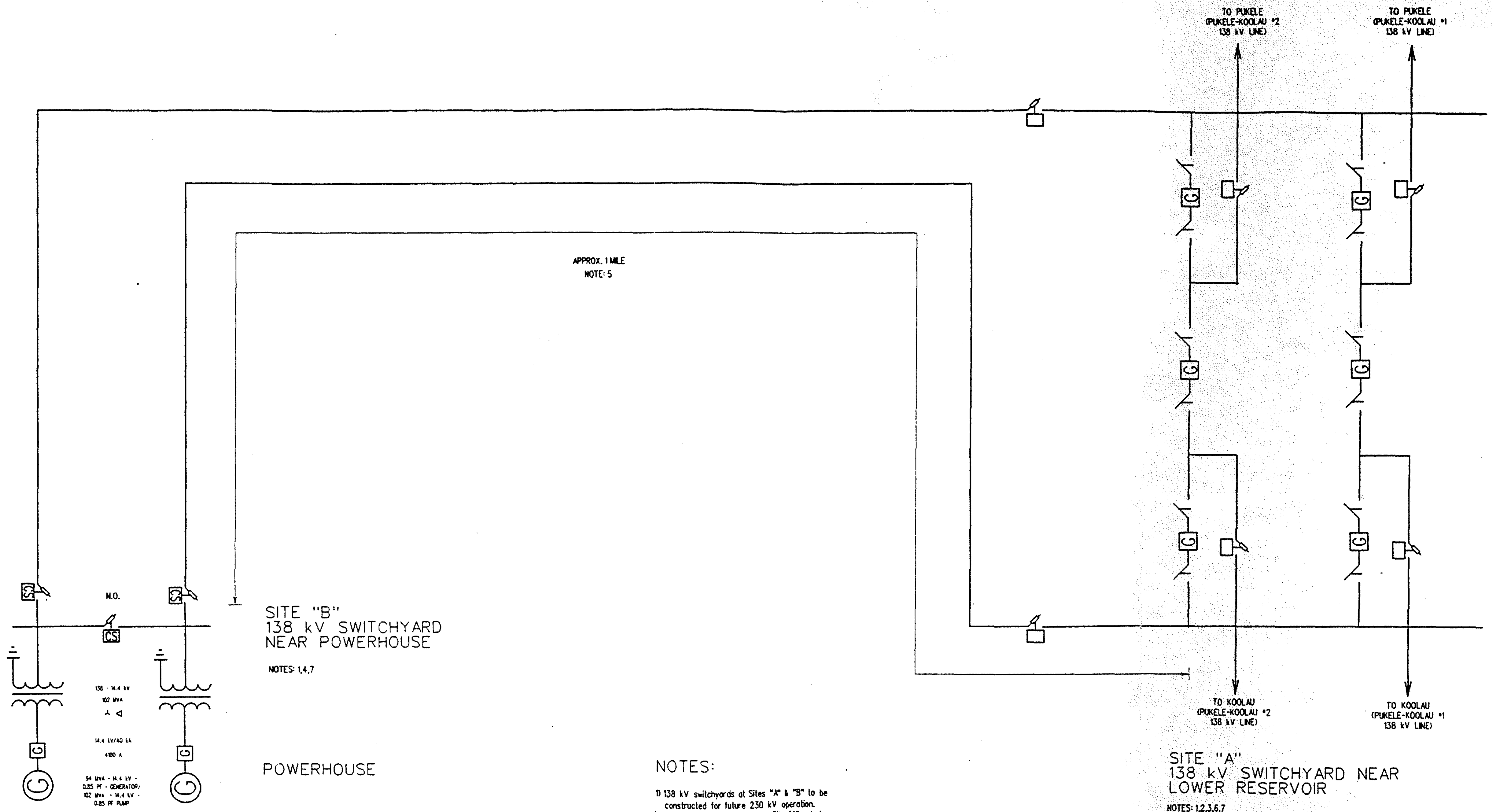


NOTES:

1) 138 kV switchyards at Sites "A" & "C" to be constructed for future 230 kV operation.
2) Assume all circuit breakers at Sites "A" and "C", except generator breakers, rated 145 kV, 40 kA and 2000 A.
3) Assume line disconnect switches at Site "A" have a minimum rating of 1640 A, at 145 kV and 40 kA, except as noted in *4.
4) Assume 138 kV lines between Site "A" and Site "C" have a minimum rating of 1300 A. Assume line disconnect switches at Sites "A" and "C" for these lines have a minimum rating of 1300 A, at 145 kV and 40 kA.
5) Assume 138 kV line protections at Site "A" to Koolau and Pukele to be similar to Kahe-CEIP *1&2, however use MW communication for LCB II relays. Include Bkr Failure DTT feature per Koolau Bus Modify project.
6) Assume 138 kV line protections for Site "A" to Site "C" to be similar to Kahe-CEIP *1 & 2 line protection. Use F.O. channels for LCB II relays.
7) Assume dual transformer differential protection between Site "C" and powerhouse.
8) Assume dual 138 kV bus differential protection at Site "C".

FIGURE III-16

pxtwskoau.sld



NOTES:

1) 138 kV switchyards at Sites "A" & "B" to be constructed for future 230 kV operation.
2) Assume all circuit breakers at Site "A" rated 145 kV, 40 kA and 2000 A.
3) Assume line disconnect switches at Site "A" have a minimum rating of 1640 A, at 145 kV and 40 kA except as noted in *5.
4) Assume circuit switchers at Site "B" have a minimum rating of 850 A, at 145 kV and 40 kA.
5) Assume 138 kV lines between Site "A" and Site "B" have a minimum rating of 850 A. Assume line disconnect switches at "Site "A" for these lines have a minimum rating of 850 A, at 145 kV and 40 kA.
6) Assume 138 kV line protections at Site "A" to Koolau and Pukele to be similar to Kahe-CEIP *1&2, however use MW communication for LCB II relays. Include Bkr Failure DTT feature per Koolau Bus Modify project.
7) Assume 138 kV line protections for Site "A" to Site "B" to be similar to new Koolau-Pukele *1&2 line protection. Include DTT from Site "B" to Site "A".

PRELIMINARY, FOR ESTIMATING PURPOSES ONLY

NO.	DATE	REVISIONS	BY	CHK'D	APP'D

PROPOSED ELECTRICAL SINGLE LINE DIAGRAM

KAAU CRATER PUMPED STORAGE - ALTERNATIVE A

DESIGNED	DRAWN WJS	DATE 01/06/1994	SCALE Not to scale
CHECKED	ELEC. MECH. STRUC.		
APPROVAL		DRAWING NUMBER	REV

06-JAN-1994 13:09 wshemley /usr/wshemley/dgn/pxtwskoau.sld

FIGURE III-17

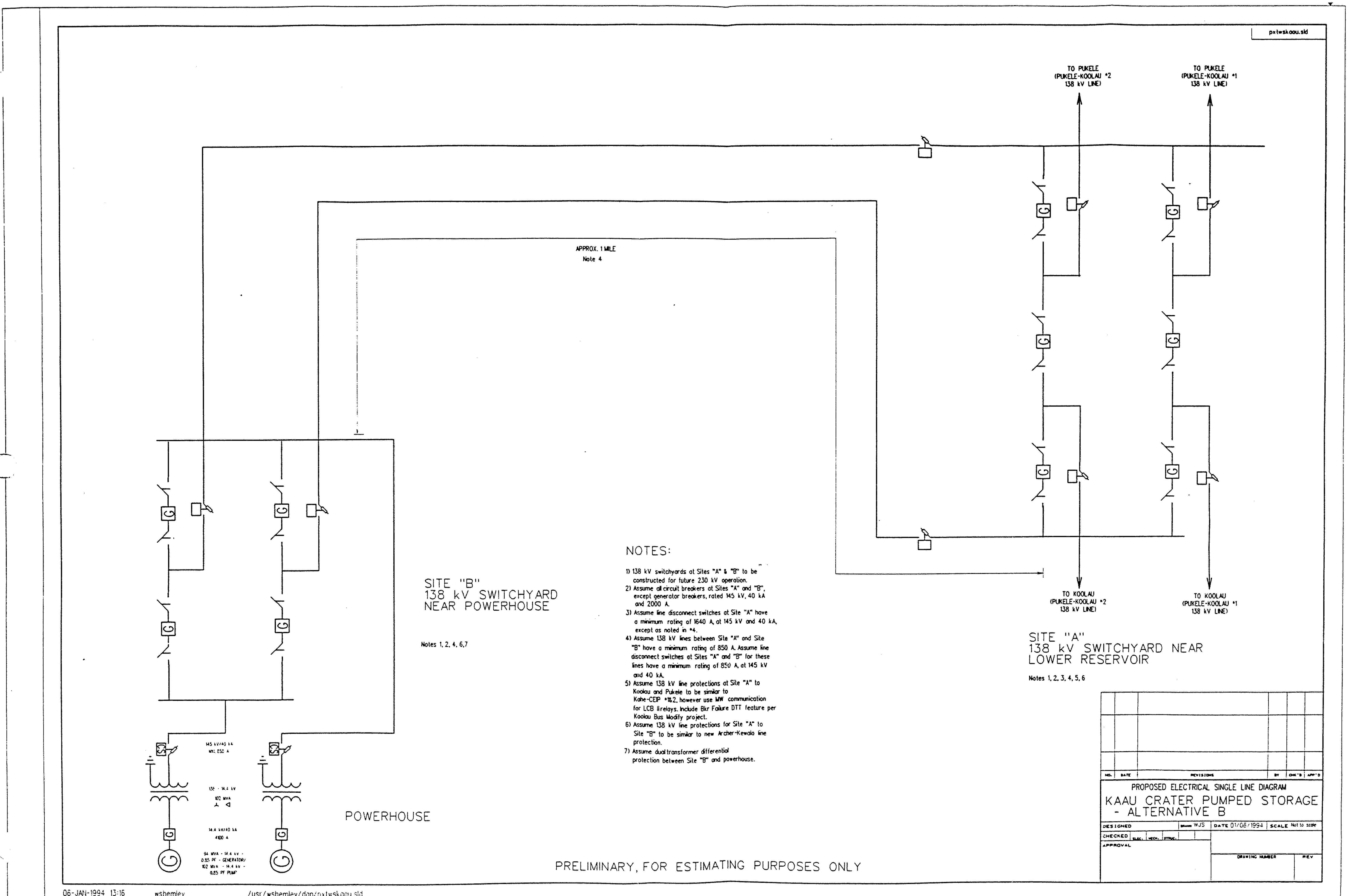


FIGURE III-18

III F. COST ESTIMATE AND CONSTRUCTION PLANNING

The estimated cost for each project was developed based on the designs described in the previous sections. The estimates are based on quantity take-offs from these designs and unit prices for Hawaii cost and productivity. There are some obvious limitations in the accuracy in the estimates since the designs are conceptual in nature; however, all the major construction elements have been costed. In addition, realistic overhead and profit percentages have been included based on the type of construction involved.

Table III-C and III-D are summaries of the costs for Koko Crater and Kaau Crater projects. Appendix J provides greater cost detail and a breakdown of the summaries.

Some of the assumptions used for the estimates are as follows;

-Drill and blasting techniques will be used to form the underground tunnels, penstocks and powerhouse on 3 shifts per day. Blasting will not be used to grade the reservoirs.

-Cut and fill will be balanced and there will be essentially no hauling. Excavated rock and soil will be processed on site.

-Material excavated from underground will be processed and used on site.

-Transmission lines will be above ground along the Koolaus. Portions of the Koko Crater transmission line will be underground between the Koolaus and the switchyard.

Schedule:

Figures III - 19 and III - 20 depict the schedule for construction of the Koko Crater and the Kaau Crater projects, respectively. These schedules are based on the experience of a similar project in Okinawa. The critical path is 1-excavation of the access tunnels, 2-excavation of the power house, 3-installation of the turbines and 4-installation of the generators. Current experience allows 18 - 20 months for lead time in procurement of large electrical machinery; this time has been included in developing the schedules. These schedules assume all the necessary planning, environmental and land use permits have been previously obtained.

Economic analysis

The estimated construction and operating costs were analyzed by Hawaiian Electric Co. to determine if the two projects were cost effective when compared to alternative generating schemes developed in the IRP. The analysis is detailed in Appendix K. The results indicate that both the Koko Crater and Kaau Crater projects have costs higher than the alternative schemes. These higher cost differences, which range from $18 to $34 millions (0.3% to 0.5%) over a period of 20 years, are not enough to eliminate the PSH projects from consideration and both projects are considered cost effective. The alternative generating schemes were the least cost plan and the preferred plan developed from the IRP.

FILE : 1194BA

TABLE III - C

REV. NO. 0 29-Mar-94

PROJECT : KOKO CRATER - PUMPED STORAGE

ITEM : PROJECT SUMMARY

SHEET 1 OF 10 PAGES

	QUANTITY	Unit	Unit Price	MAT'L & SUB	Unit Price	LABOR & EQUIPT	Unit Price	TOTAL
SUMMARY DIRECT COST CONSTRUCTION								
A. MOBILIZATION				1,180,000		350,000		1,530,000
B. SPECIAL PLANT				320,000		10,000		330,000
1. UPPER RESERVOIR				18,541,000		11,630,000		30,171,000
2. INTAKE STRUCTURE				1,787,000		1,068,000		2,855,000
3. i) PENSTOCK TUNNEL				7,144,000		5,673,000		12,817,000
ii) DRAFT TUBE TUNNEL				887,000		1,034,000		1,921,000
iii) TAILRACE TUNNEL				2,625,000		2,965,000		5,590,000
4. POWERHOUSE				5,677,000		7,040,000		12,717,000
5. DRAFT GATE HALL				2,253,000		740,000		2,993,000
6. OUTLET STRUCTURE				12,596,000		6,231,000		18,827,000
7. POWERHOUSE ACCESS				5,591,000		6,209,000		11,800,000
8. OUTLET ACCESS TUNNEL				949,000		2,263,000		3,212,000
9. POWERHOUSE EQUIPMENT (#1)				40,290,000				40,290,000
10. SWITCHYARD				14,348,000				14,348,000
11. TRANSMISSION LINE (#2)				7,861,000				7,861,000
TOTAL DIRECT COST				122,049,000		45,213,000		167,262,000
CONTRACTORS OH	15.00%							25,089,000
SUBTOTAL								192,351,000
CONTRACTORS CONTINGENCY & FEE	15.00%							28,853,000
SUBTOTAL								221,204,000
BOND & HAWAII G.I. TAX	4.50%							9,954,000
DESIGN / CM	6%							13,869,000
TOTAL PROJECT 1994 DOLLARS								245,027,000
OWNERS CONTINGENCY	5%							12,251,000
MITIGATING MEASURES	1%							2,450,000
TOTAL CONSTRUCTION 1994 DOLLARS								259,728,000
LAND AQUISITION (#3)								TO BE DETERMINED

(#1) INCLUDES PRIMARY TRANSFORMERS

(#2) ALLOWS $ 2,000,000 FOR UNDERGROUND PORTION OF TRANSMISSION LINE

(#3) VALUE BASED ON CURRENT TAX ASSESSMENT OF $1,200 / ACRE

FILE : 1194BB

TABLE III - D

REV. NO. 0 29-Mar-94

PROJECT : KAAU CRATER – PUMPED STORAGE

ITEM : PROJECT SUMMARY

SHEET 1 OF 12 PAGES

	QUANTITY	Unit	Unit Price	MAT'L & SUB	Unit Price	LABOR & EQUIPT	Unit Price	TOTAL
SUMMARY DIRECT COST								
A. MOBILIZATION				1,230,000		375,000		1,605,000
B. SPECIAL PLANT				380,000		10,000		390,000
1. UPPER RESERVOIR				12,427,000		5,573,000		18,000,000
2. UPPER RESERVOIR ACCESS ROAD				924,000		308,000		1,232,000
3. INTAKE STRUCTURE				476,000		223,000		699,000
4. WATER CONDUCTORS								
i) PENSTOCK TUNNEL				6,648,000		7,579,000		14,227,000
ii) DRAFT TUBE TUNNEL				434,000		453,000		887,000
iii) TAILRACE TUNNEL				2,767,000		2,875,000		5,642,000
5. POWERHOUSE				5,545,000		7,124,000		12,669,000
6. SURGE TANK				1,725,000		2,050,000		3,775,000
7. DRAFT GATE HALL				1,207,000		713,000		1,920,000
8. TAILRACE GATE SHAFT				1,781,000		1,555,000		3,336,000
9. LOWER RESERVOIR				8,865,000		9,430,000		18,295,000
10. OUTLET STRUCTURE				375,000		297,000		672,000
11. CONNECTED POND				7,439,000		5,901,000		13,340,000
12. POWERHOUSE ACCESS TUNNEL				9,110,000		10,068,000		19,178,000
13. POWERHOUSE CABLE TUNNEL				2,144,000		2,310,000		4,454,000
14. ACCESS TUNNEL FOR SURGE TANK				1,950,000		1,377,000		3,327,000
15. POWERHOUSE EQUIPMENT (#1)				35,000,000				35,000,000
16. SWITCHYARD				7,246,000				7,246,000
17. TRANSMISSION LINE				507,000				507,000
TOTAL DIRECT COST				108,180,000		58,221,000		166,401,000
CONTRACTORS OH	15.00%							24,960,000
SUBTOTAL								191,361,000
CONTRACTORS CONTINGENCY & FEE	15.00%							28,704,000
SUBTOTAL								220,065,000
BOND & HAWAII G.I. TAX	4.50%							9,903,000
DESIGN / CM	6%							13,798,000
TOTAL PROJECT 1994 DOLLARS								243,766,000
OWNERS CONTINGENCY	5%							12,188,000
MITIGATING MEASURES	1%							2,438,000
TOTAL CONSTRUCTION 1994 DOLLARS								258,392,000
LAND AQUISITION (#2)								TO BE DETERMINED

(#1) INCLUDES PRIMARY TRANSFORMERS

(#2) VALUE BASED ON CURRENT TAX ASSESSMENT OF $1,200 / ACRE

Koko Crater - Pumped Storage Project Schedule

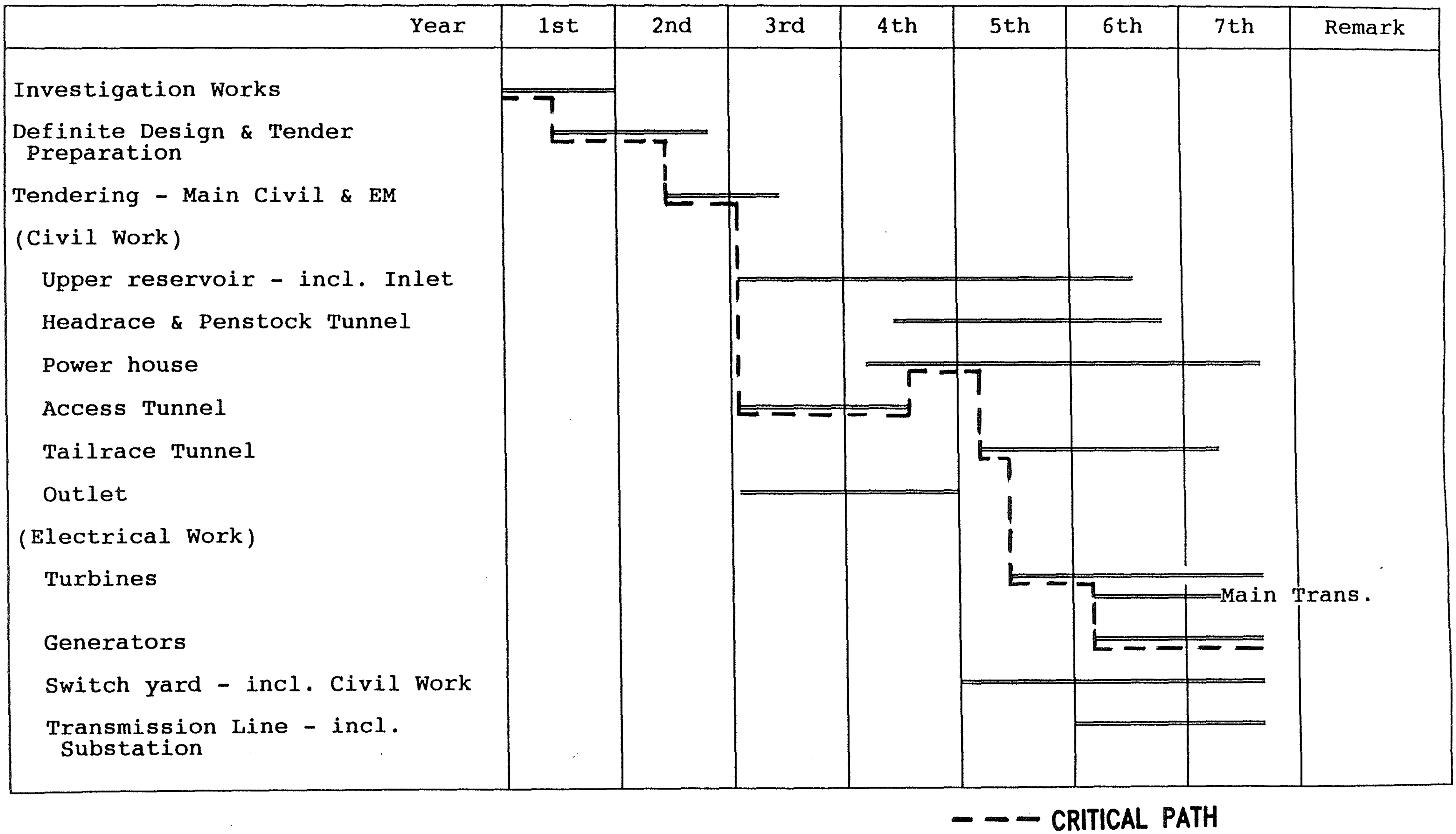


FIGURE III-19

Kaau Crater - Pumped Storage Project Schedule

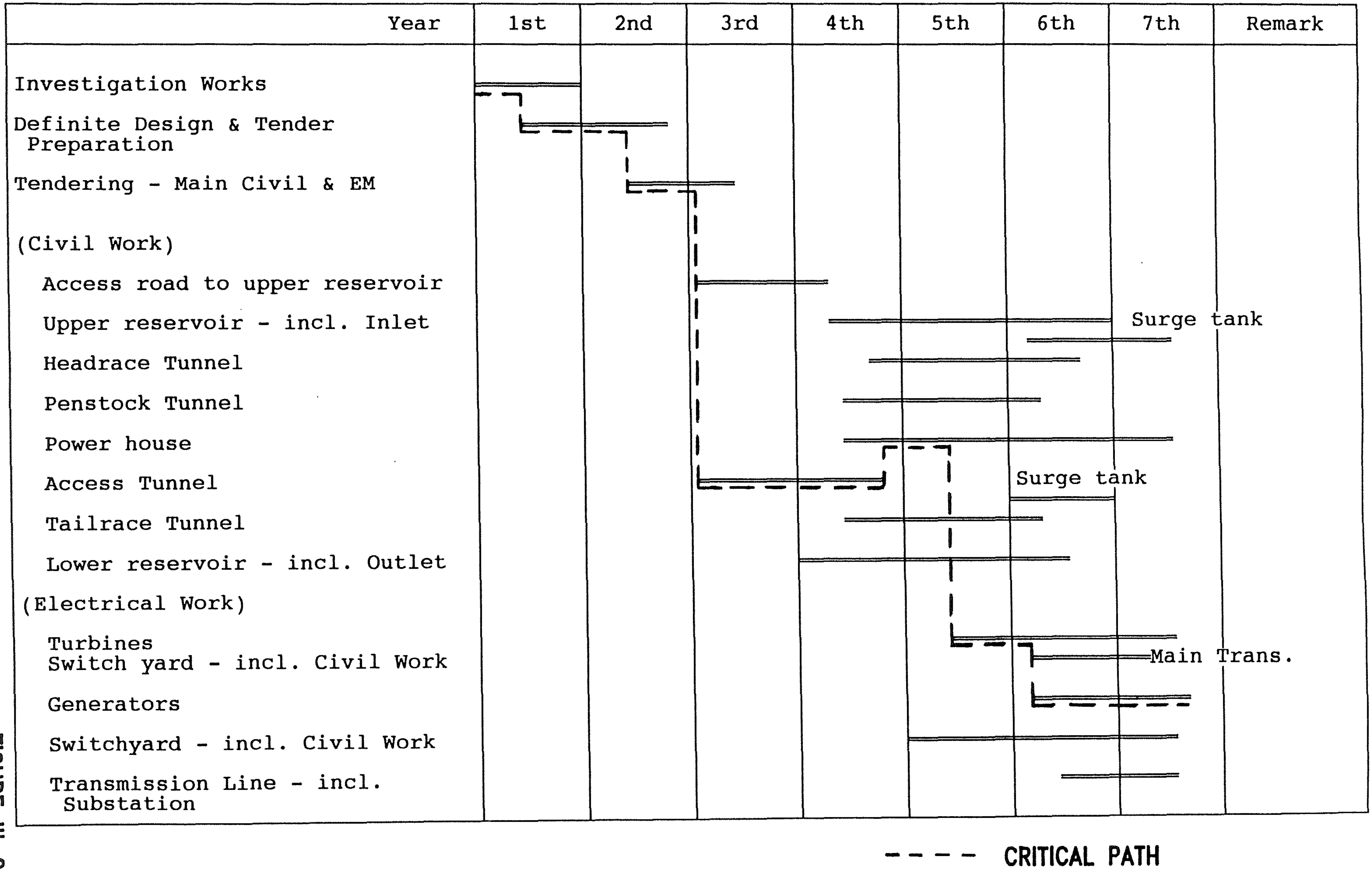


FIGURE III-20

REFERENCES

1. "Water Resources of Windward Oahu", Hawaii 1969. USGS
K. J. Takasaki, G. K. Hirashima, E. R. Lubke

2. "Evaluation of Major Dike-Impounded Ground-Water Reservoirs, Island of Oahu". 1985. USGS K. J. Takasaki and J. F. Mink.

3. "State Water Projects Plan" Review draft, February 1992.